**FEBRUARY 1953** 

# Chemical Engineering Progress

PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

### users of chemical process



### and industrial gases

get rid of



weather-worries and operating costs

with the ...

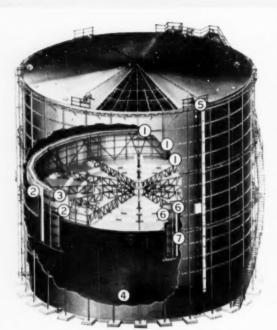
# Wiggins Gasholder

### by GENERAL AMERICAN

More than 50 users of Wiggins Gasholders can now testify to the remarkable savings in operating costs and maintenance expense which only this 100% dry seal gasholder (no water, no tar, no grease) gives them. Write for full information.







PISTON RISES NEARLY TO TOP—MINIMUM OF WASTE SPACE
CAN BE BUILT ANY SIZE • NO CONTAMINATION OF GAS

- TOP SECTION OF
  SHELL COMPLETELY
  VENTILATED
- 2 SIMPLIFY OPERATION
- GAS-TIGHT FRICTIONLESS

  3 SEAL NOT AFFECTED
  BY WEATHER
- PISTON RESTS ON 4 BOTTOM—LESS THAN 1/5 OF 1% FOR PURGING
- 5 SIDE WALL-KEEPS
  PISTON LEVEL
- 6 FENDERS PREVENT
- 7 SHELL IS GAS-TIGHT UP





#### CONVERSION EASY — OFTEN ADDS CAPACITY

Your old gasholder can be quickly converted to a Wiggins type with all the Wiggins advantages.



#### GENERAL AMERICAN TRANSPORTATION CORPORATION

135 South LaSalle St. • Chicago 90, Illinois OFFICES IN PRINCIPAL CITIES

Export Dept.: 10 East 49th Street, New York 17, New York Plunts: Birmingham, Ala. \* East Chicago, Ind. \* Shoron, Pa. In Camada: Taronto Iron Works, Ltd., Taronto, Ontario

Chemical Engineering Progress

FEBRUARY 1953

Volume 49

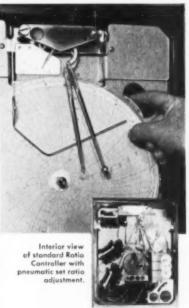
Number 2

Editor: F. J. Van Antwerpen

OPINION AND COMMENT							
BUSINESS	RECESSION IN 1954?						
	C. G. Kirkbride		53				
ENGINEERIN	IG SECTION						
GRINDIN	G AND CRUSHING-						
	FUNDAMENTAL ASPECTS	OF CRUSHING					
		S AND WHEN TO USE THEM	56				
	H. W. Erickson UNUSUAL TECHNIQUES IN	GRINDING					
	J. H. Foote	********************	68				
METERIN	G LIQUID SULFUR		70				
		and J. R. West	73				
FLASH V	MASS-TRANSFER PROBLEM		70				
		and C. V. Sternling	. 78				
STUDIES	ON THE MOTION OF GAS F. N. Peebles and H. J. G	arber	. 88				
DISTILLA	TION OF HARDWOOD IN A	rong, and H. C. Lewis	98				
VACIIIIA	ENGINEERING-	, and the decision of the second					
170011		STEAM-JET VACUUM EQUIPMEN	Т				
	D. H. Jackson EVAPORATION FROM LIQU	DIDS IN HIGH VACUUM	. 102				
	K. C. D. Hickman and D.	J. Trevoy	. 105				
CEMENT	EQUIPMENT REFERENCE SH. R. H. Steiner and W. R. Pa	HEET scoe	. 110				
NEWS	Page		Page				
			-				
	MEETING 31 INICAL PROGRAM 32	A.I.Ch.E. CANDIDATES LOCAL SECTION					
INDUSTRIAL NEWS 34 FLITTIDE MEETINGS							
DATA :	SERVICE	NEWS ABOUT PEOPLE					
COUN	CIL REPORT 55	CLASSIFIED					
SECRET	ARY'S REPORT 56	NECROLOGY					

Published monthly by American Institute of Chemical Engineers, at 15 North Seventh Street, Philadelphia 6, Pennsylvania, Editorial and Advertising Offices, 129 East 41st Street, New York 17, N. Y. Communications should be sent to the Editor. Statements and opinions in Chemical Engineering Progress are those of the contributors, and the American Institute of Chemical Engineers assumes no responsibility for them. Subscriptions: U. S. and possessions, \$6,00; Canada, \$6,50; Pan-American Union, \$7.50; Other Foreign, \$8.00. Single copies of Chemical Engineering Progress older than one year cost \$1.00 a copy; others are 75 cents. Entered as second class matter December 9, 1946, at the Post Office at Philadelphia, Pennsylvania, under the Act of August 24, 1912. Copyright 1953 by American Institute of Chemical Engineera. Member of Audit Bureau of Circulations. Chemical Engineering Progress is indexed regularly by Engineering Index, Incorporated.

# PEW FISCHER & PORTER OUTOMOTIC FLOW RATIO CONTROLLER



Compact size with extreme precision of ratio control are important advances in this new Fischer & Porter Ratio Controller, Designed specifically for flow ratio control, it makes a perfect combination teamed with the new P-4 Pneumatrol and highly accurate Flowrator meters or V/A Cell kinetic manometers, to assure accurate and dependable ratio control of fluids, gases or slurries. Receives pneumatic, electrical, or electronic primary signals. Review the features below, then send for complete engineering and application data.

#### CHECK THESE FEATURES:

- Extreme flexibility
- . Wide range of ratio (36:1)
- · Based on linear scale primaries
- Control deviation indicator
- · Primary element fully corrosion resistant
- · Highly visible ratio setting dial
- Extremely compact stack mounting

#### FISCHER & PORTER



120 County Line Road Hatboro, Penna.





infra-red analysis tells how much of a selected component exists in gas mixtures. Here, continuous analysis recorded by an Electronik potentiometer on a refinery's graphic panel is used for actual process control.



mass spectrometry separates materials on the basis of their different molecular weights... finds what constituents are present in what quantity. Above is a "package" mass spectrometer in which an ElectroniK instrument records test data.



gas analyzer, operating on the thermal conductivity principle, combines an ElectroniK recorder, analysis cell and accessories in a single panel assembly.

# New concepts utilize

### These are some of the manufacturers who use ElectroniK instruments in their analyzers

Products of the companies checked are illustrated on these pages

Applied Research Laboratories

√ Baird Associates

Bausch and Lomb

Beckman Instruments, Inc.

Consolidated Engineering Corporation

√ Davis Emergency Equipment Co.

General Electric Co.

Jarell-Ash

Mine Safety Appliances Co.

North American Philips Co., Inc.

Perkin-Elmer Corp.

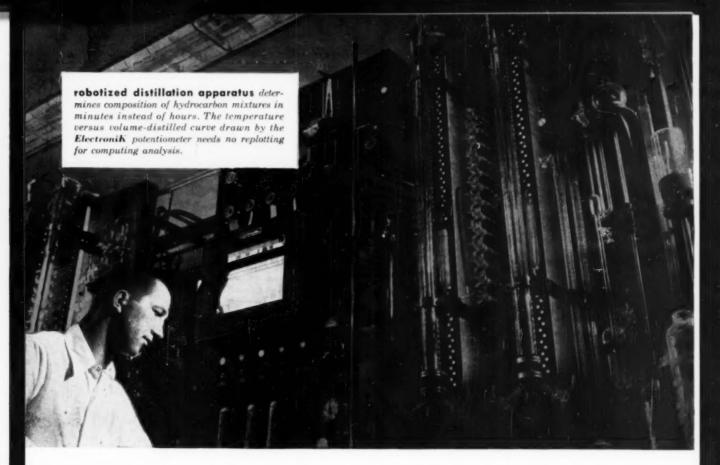
v Podbielniak, Inc.

Precision Scientific Co.

E. H. Sargent & Co.

Tracer Laboratories

Turner-Burrell Technical Supply Co.



# of process control Electronik instruments

From the analytical laboratory comes a new concept of industrial process control, based directly on the desired chemical or physical characteristics of the product.

Continuous analyzers now make it possible to measure composition of gases and liquids accurately and automatically . . . to record this information . . . even to actuate automatic controls. Instead of temperature, pressure and flow, these new systems deal in terms of refractive index, density, ultraviolet and infrared spectra, radiation intensity and absorption.

An essential component of all these systems is automatic recording. To fill this critical function, leading manufacturers of automatic analyzers choose ElectroniK instruments. They choose them

for their exceptional accuracy, that exploits fully the inherent precision of the new measuring techniques. They choose them, too, for sensitivity that records every essential change in readily readable detail. And they prefer *ElectroniK* recorders for their simple, rugged design that guarantees dependable service under any industrial conditions.

Your local Honeywell engineering representative will be glad to discuss the role of *ElectroniK* instruments in product-analysis systems . . . or in any conventional process control. Call him today . . . he is as near as your phone.

MINNEAPOLIS-HONEYWELL REGULATOR Co., Industrial Division, 4427 Wayne Ave., Philadelphia 44, Pa.

REFERENCE DATA: Write for Bulletin 15-14, "Instruments Accelerate Research."



Honeywell

First in Controls

FOR SEVERE THROTTLING AND FLOW CONTROL SERVICES .

# NEW

#### CRANE-PAUL

Venturi-Ball

(Patented and Patents Pending)

CAST STEEL OR CRANE 18-8Me ALLOY Outside Screw and Yoke—Flanged. Available with sliding stem for assembly with power operators.

Meet the Crane-Paul Valve—a unique design that combines desirable advantages of both gate and globe valves. It provides better service and longer life under more rigorous operating conditions than such valves normally stand. These features include—

Exceptionally accurate throttling with a minimum of wear and erosion, resulting in longlived seating surfaces.

Straight-through, non-turbulent flow-with pressure drop characteristics approaching those of venturi-type gate valves.

Smooth, easy response throughout the entire range of operation.

Completely tight shut-off.

Heart of this new Crane-Paul Valve is a precision-ground ball disc which rides loosely in a cage direct-connected to the valve stem. In operation, the ball is moved to and from the center of flow and rolls into and out of the body seat. At no time during valve operation does the ball spin or chatter, even in closely throttled positions. It revolves just enough to provide a new seating surface each cycle. In the closed position, part of the ball actually protrudes into the outlet port where it is tightly seated by the wedging action of the ball cage.

#### Literature Sent on Request

Full information on this new Crane-Paul Valve is in your Crane 53 Catalog. Literature is available from your Crane Representative or on request to address below.

# JALVES

Inclined surfaces in

Cast Steel
150-Pound, Sizes 1 through 6"
300-Pound, Sizes 1 through 8"
600-Pound, Sizes 1 through 4"

Crane 18-8Mo Alloy 150-Pound, Sizes 1 through 6" 300-Pound, Sizes 1 through 8"

for

### CRANE VALVES

CRANE CO., General Offices: 836 S. Michigan Ave., Chicago 5, Illinois Branches and Wholesalers Serving All Industrial Areas

VALVES . FITTINGS . PIPE . PLUMBING . HEATING

# the 20C's

ST. GOBAIN

PROCESS FOR THE MANUFACTURE
OF GRANULATED COMPLETE FERTILIZERS

dvantages

The St. Gobain process manufactures complete Nitrophosphate granulated fertilizers in one continuous automatic operation. Its extreme flexibility permits the production of various nitrogen-phosphorous-potash formulae without altering the equipment.

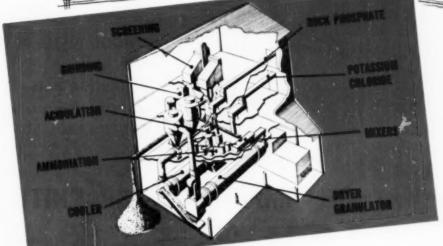
enefits

You benefit from the improvements made during the ten years of successful industrial operation. The St. Gobain system reduces the sulphuric acid consumption by replacing it with nitric acid. No phosphate rock grinding is necessary.

apital

Investment and operating costs are low due to simple equipment, continuous operation, and to a very high yield.

St. Gobain plants are built for 30,000 tons of fertilizers yearly capacity and up.



or further information write to the agents for St. Gobain processes:



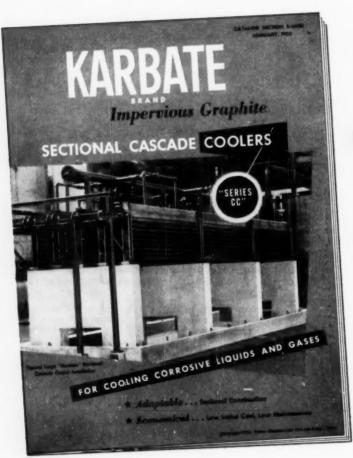
Jeneral DEVELOPMENT

270 PARK AVENUE, NEW YORK 17, N. Y.

EXAMPLES OF FORMULAE
PRODUCED BY ST. GOBAIN PROCESS

N96	P.O.%	K-0%			
10	10	17	(sulfo	-nitric	acidulation)
11	11	11	**	2.6	**
10	15	20	(phosph	o-nitri	c acidulation
12	15	18	**	**	**
12	12	20	**	**	**
14	14	14	**	**	**
10	20	20	**	**	48

# GREATER VALUES IN...



# NEW "SERIES CC" "KARBATE" SECTIONAL CASCADE COOLERS

- HIGH HEAT TRANSFER RATE
- **LOW INITIAL COST**
- HIGH COOLING WATER CAPACITY
- TYPE SN ARMORED CONNECTIONS
- RADIUSED RETURNS FOR LOW PRESSURE DROP
- REDWOOD WATER GUIDE STRIPS
- **•**"TEFLON" GASKETS
- THREE STANDARD MODELS
   AVAILABLE FROM STOCK

# ...ALL "KARBATE" IMPERVIOUS GRAPHITE EQUIPMENT GIVES YOU:

**OUTSTANDING CORROSION RESISTANCE** 

**COMPLETE IMMUNITY TO THERMAL SHOCK** 

**•FREEDOM FROM METALLIC CONTAMINATION** 

**eLONG LIFE—LOW MAINTENANCE** 

### ...A CONSTANTLY IMPROVING LINE

<u>Specify</u> "National" Carbon and Graphite and "Karbate" Impervious Graphite Equipment for Processing, Conveying and Storing Corrosive Fluids.



#### HEAT EXCHANGERS

Wide variety of standard and custombuilt models in time-proved designs. Shell and tube, concentric and immersion types available in stock sizes. Catalog Sections S-6620, S-6670, S-6740, S-6750.

#### **PUMPS**

The centrifugal pump for handling corrosive fluids. Rugged, trouble-free design. Handling capacities to 800 G.P.M. Catalog Section S-7200.

#### PIPE, FITTINGS and VALVES

For industry's toughest fluid conveying requirements. Easy to install and maintain with simple hand tools. Catalog Section S-7000.

#### BRICK

Accepted material for lining tanks, towers, digesters and other vessels containing corrosive chemicals. Catalog Section S-6210.

#### **GROUND ANODES**

"National" Graphite Ground Anodes for cathodic protection of buried or submerged metal structures. Catalog Section S-6510.

#### STEAM JETS

For heating and agitating corrosive solutions by direct injection of steam. Catalog Section S-7300.

#### TOWERS

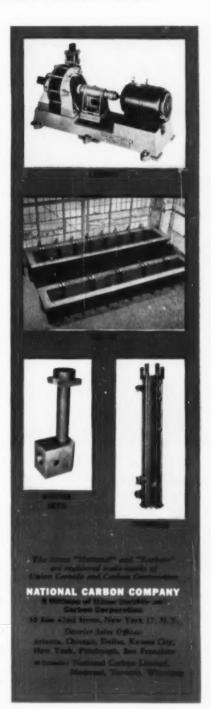
For absorption, fractionation and scrubbing. Easily erected from standard monolithic sections and components. Catalog Section S-7350.

#### **HCL COMBUSTION CHAMBERS**

Versatile, standard equipment for hydrogen chloride synthesis. Burns moist gases. Simple in operation. Catalog Section S-7530.

#### **HCL ABSORBERS**

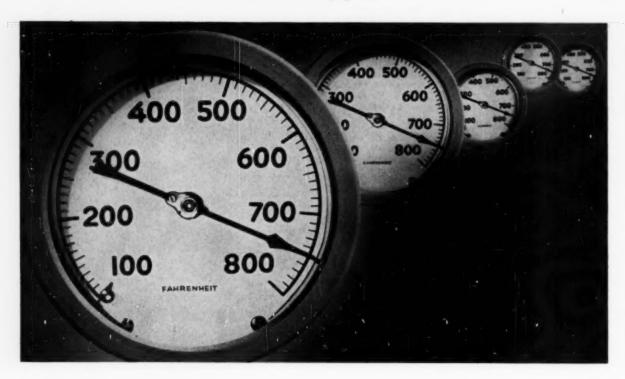
Standard and custom-built models to meet any hydrochloric acid production requirement. Catalog Section S-7430.





## UNIFORM HEAT FOR PROCESS INDUSTRIES

DOWTHERM gives you constant heat, controlled within fractions of a degree . . . eliminates spoiled batches, uneven heating problems



Dowtherm® assures precise control over the entire process heating surface uniformly at temperatures up to 750°F. With this modern heat transfer medium you can eliminate hot spots and overheating that cause ruined batches or runs . . . and save money on your heating costs, too.

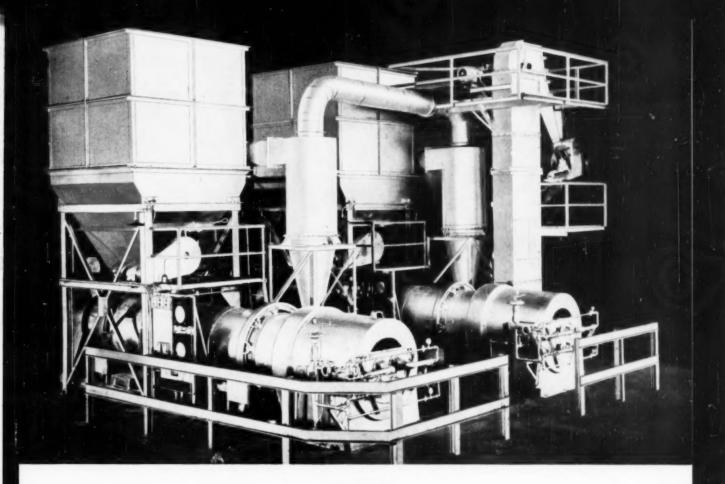
A liquid material used as a vapor heating medium in an entirely closed system, Dowtherm operates at high temperature, low pressure, and extends the advantages of ordinary steam-type heating to a much higher range of operating temperatures.

Dowtherm was created by the Dow research team for the chemical, petroleum, paint, food and other process industries—has helped to increase production and even made possible new products.

Countless installations have thoroughly proved the efficiency and cost reducing potentialities of Dowtherm. For complete information on these benefits and how they apply to your industry, write to the dow Chemical Company, Midland, Michigan, Department DO 3-3.

you can depend on DOW CHEMICALS





# compact Twin Dryer installation



Calciner and Cooler for Continuous Processing at Temperatures from 900°F, to 2100°F,



Special Stainless Steel Batch Dryer for Drying Fine Catalyst without Dust Loss.

#### handles wide load fluctuations

• Consisting of two complete, self contained units, the twin systems pictured above can be operated together — or singly — depending upon plant requirements. Burners on each dryer are controlled separately, and automatically, for maximum fuel economy and to assure the discharge of a product having constant and uniform dryness regardless of variations in the rate, or moisture content of the feed. Highly efficient and thoroughly dependable, this is another example of Bartlett-Snow's skillful and detailed approach to every drying problem — your assurance that the diameter and length of shell, pitch, rate of feed and all other specifications of the equipment furnished will be exactly suited to your particular requirements. Let us work with you on your next job.

DESIGNERS BARTLETT FABRICATORS
ENGINEERS CLEVELAND 5, ONIO

Dryers · Coolers · Calciners · Kilns
"Builders of Equipment for People You Know"



# when you specify light wall schedule 5 pipe

#### WHAT SCHEDULE 5 PIPE IS-

A light wall pipe, Carpenter Schedule 5 gives you more feet of pipe for every pound of scarce stainless steel. So you can quickly see how Schedule 5 reduces your cost per foot. Plus the fact that the larger I.D. means increased flow area.

#### **HOW SCHEDULE 5 REDUCES COSTS**

First saving is 40% to 50% on the cost of your pipe.

Since Schedule 5 is considerably lighter, this means quicker and easier installation.

And, because the increased capacity of Schedule 5 lets you use the next smaller pipe size, you can reduce substantially your costs of valves, fittings, etc.

#### FITTINGS ARE AVAILABLE

This pipe is easily adapted to use with existing lines

of tubing or Schedule 40 and 10 pipe, using simple connectors. Fittings as well as stocks of Schedule 5 pipe are carried by conveniently located Carpenter distributors.

#### ADDITIONAL ADVANTAGES

Tubing sizes can now be replaced with light wall pipe...for ready hook-up with standard valves, pumps and other equipment which is normally manufactured in pipe sizes.



Data Sheets give you complete information about Carpenter Schedule 5 Stainless Pipe. Write for your personal copy. THE CARPENTER STEEL COMPANY, Alloy Tube Division, Union, N. J.

Export Dept.: The Carpenter Steel Co., Port Washington, N.Y. "CARSTEELCO"



- guaranteed on every shipment

# again.... it's Pacific!

First To Offer A Complete Line of Stainless Steel Valves, Designed to Fit Your Job . . . Pricewise!

The Pacific line of Stainless Valves has been extended to include several series of valves, each tailored to do a big job, in the right place, at the right price. No longer is it necessary to install expensive high pressure stainless valves for low pressure services.

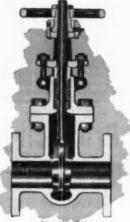


Fig. No. 500 150 Lb. Gate Valve

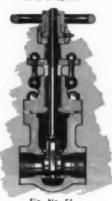


Fig. No. 51 600 Lb., Gate Valve



Fig. No. 350 Typical A. S. A., A. P. I. Gate Valve

The newest addition to Pacific's line is the light-weight patterned Gate Valves, Fig. No. 8550 & 8551, (150 Lb. Series) conforming with specifications of the Manufacturers Standardization Society. Although competitively priced, this series maintains Pacific's rigid policy of high standards of quality in workmanship and materials. Pacific's corrosion resistant, solid wedge Gate Valves, Fig. No. 500 & 501, (150 Lb. Series) are premium quality valves having design features and metal proportions beyond normal corrosion resistant requirements, and are unexcelled in this pressure classification.

Pacific's Fig. No. "500 ASA" Gate Valves are identical to Fig. No. "500" except that both pipe line flanges and bonnet flanges are heavier and the line flanges are machined with a 36" raised male face in accordance with A.S.A. specification B-16E. This valve is used in both old and new installations where service conditions require additional bolting and safety factors beyond the capabilities of the lightweight, flat faced flanges.

Pacific's ASA Flanged Ends (Series 150, 300 and 600), Screwed Ends (Series 600), Solid Wedged, Bolted Bonnet, O.S. & Y., Cast Stainless Steel Valves, sizes 1/2" through 2", offer new and improved design features usually found only in larger size, more expensive valves. These valves are low in cost, unusually compact and rugged and are constructed of high quality materials and manufactured to exacting standards.

Pacific's regular line of Stainless Valves includes 150 Lb. Check Valves and Globe Valves, designed to M.S.S. Specifications.

In addition to Pacific's Standard Line of Corrosion Resistant Valves, its entire line of Cast Steel Gate, Globe, Angle and Swing Check Valves, 150 Lb. through 1500 Lbs., is produced in corrosion resistant alloys.

This wide Series of Stainless Valves and the many combinations of Trim materials available enables Pacific to furnish valves for all service conditions.

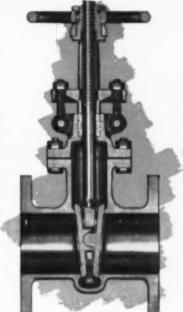


Fig. No. 8550 Lightweight Pattern 150 Lb., Gate Valve

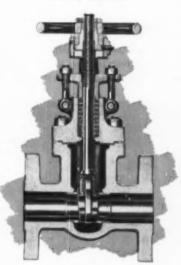


Fig. No. 3350 300 Lb. Gate Valve A. S. A. Flanges

Write or Telephone for Additional Information!

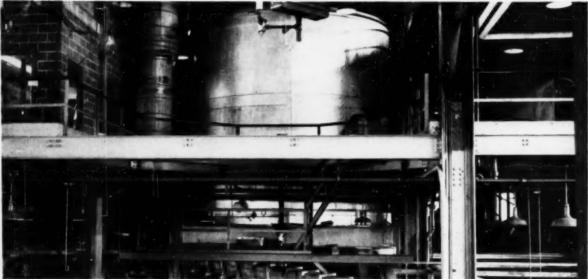
### PACIFIC VALVES, INC.

Manufacturers of Pacific Cast, Forged and Stainless Steel Valves

3201 WALNUT AVENUE . LONG BEACH 7, CALIFORNIA

TELEPHONES: Long Beach 40-5451; Los Angeles NEvada 6-2325
TELETYPES: Long Beach 8-8076; New York City - NY 1-1077; Houston, Tex. - HO 489

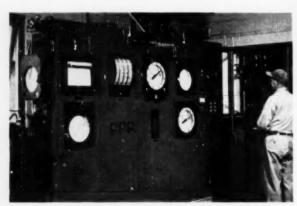
Sales Offices In All Principal Cities



General view of Brown Company Reactor

# First Dorrco FluoSolids\* Reactor For Producing SO<sub>2</sub> Goes "On Stream" at Brown Company

**BERLIN, N. H.** In anticipation of a continuing sulfur shortage, The Brown Company at Berlin, N. H. recently installed a Dorrco FluoSolids System to produce  $SO_2$  gas from pyrrhotite. The System at the present time is supplying the entire sulfur requirements of this sulfite pulp mill . . . 11,000 tons of sulfur equivalent per year. A producer of quality pulp for high-grade photographic papers, Brown requires clean, high-strength  $SO_2$  gas to make their sodium sulfite cooking liquor.



Centralized control panel

#### **RAW MATERIAL FORMERLY A WASTE PRODUCT**

The pyrrhotite, recovered from tailings of a nearby copper mine, is received in a moist condition, repulped with water to 70-75% solids, and pumped into the Reactor. By operating close to theoretical oxygen requirements, the strongest possible SO<sub>2</sub> gas is produced, with a black magnetite calcine which is quenched and

\* Trademark Reg. U. S. Pat. Off.

handled in slurry form. Roast is accomplished in a 16' inside diameter Reactor with the temperature automatically held at 1650°F.



Clamshell discharging pyrrhotite into blunger

#### HIGH STRENGTH SO2 PRODUCED

Gas strength at the top of the Reactor averages 13% SO<sub>2</sub>. The gas then passes through a two-stage cyclone system followed by a cooling-scrubbing tower before going to the acid towers. Average chemical analysis of feed and calcine follows:

	<b>Total Sulfur</b>	Sulfide Sulfur	Total Fe
Pyrrhotite Feed	35.7	35.6	49.1
Combined Calcine	0.51	0.49	60.9

For detailed information about Fluo-Solids — a distinct departure from conventional roasters — write for Bulletin No. 7500. The Dorr Company, Stamford, Conn. or in Canada, The Dorr Company, 80 Richmond Street West, Toronto 1.



### An unbeatable team for temperature measurement

# DYNALOG RECORDERS and DYNATHERM BULBS



You can't beat this Foxboro Dynalog-Dynatherm combination for insuring better temperature measurement on any job between-100° and+600°F. It gives you every advantage of speed, accuracy, long leads, simple installation, economy, and freedom from maintenance. This is why:

The Dynalog Electronic Recorder has an exclusive variable-capacitor measuring system which eliminates slidewires, gears, cables, high speed balancing motors . . . no dead space, no batteries to standardize, no motors to service. Standard full-scale pen speed only 3 seconds. Sustained accuracy 1/4 of 1% guaranteed. Available for spans as narrow as 5°F. with full-accuracy calibration.

The Dynatherm Resistance Bulb has unique features including metal-to-metal end-contact which, when installed in a well or socket, gives a speed of response unsurpassed by any other similarly protected temperature-sensitive element. Exceptionally rugged and permanent in calibration.

These are only a few of the important advantages of this better temperature measuring system . . . available also for control of temperatures, or with Multi-Record Dynalog for up-to-6 records on one chart. Write for full details. The Foxboro Company, 932 Neponset Ave., Foxboro, Mass., U.S.A.





INSTRUMENTATION

FACTORIES IN THE UNITED STATES, CANADA, AND ENGLAND





## Making a little cleanser go a long way

SINCE HOUSEHOLD CLEANSERS are one of many products that require bulk in order to do their work efficiently and economically . . . it is not surprising to find Celite Mineral Fillers used as a standard ingredient in quality cleansers.

The reason is the great bulk per unit of weight of Celite Mineral Fillers...as

well as their exceptionally low cost per unit of volume. In addition, they have a high absorptive capacity for perfumes and chemicals. Celite's porous, thinwalled cellular structure, from which these advantages are derived, adapts these diatomaceous silica powders to numerous industrial uses.

#### THESE CELITE PROPERTIES BENEFIT MANY TYPES OF PRODUCTS

Celite Mineral Fillers are composed of minute, multi-shaped particles that interlace to stiffen and strengthen admixtures. The microscopically small facets of these particles diffuse light so effectively that they can be utilized to impart any desired degree of flatness to a surface film. Their light, porous nature improves suspension, helps prevent segregation. Their high absorption properties and unique diatom

structure make them unusually effective for overcoming caking in deliquescent materials.

If you are looking for the "extra something" to lift your product above competition—at no extra cost—why not discuss your problem with a Johns-Manville Celite Engineer? For further information and samples, write Johns-Manville, Box 60, New York 16, New York. In Canada: 199 Bay Street, Toronto, Ontario.

CHECK LIST OF PRODUCT BENEFITS OBTAINABLE AT LITTLE COST WITH CELITE MINERAL FILLERS

- Added Bulk
- Better Suspension
- Faster Cleaning Action
- Greater Absorption
- Improved Color
- Better Dielectric
  Properties
- More Durable Finish
- Increased Viscosity
- Elimination of Caking
- Higher Melting Point
- Better Dry Mixing
- Improved Dispersion



### Johns-Manville CELITE

MINERAL FILLERS



#### IN ENGINEERING AND CONSTRUCTION

Fluor's Engineering and Construction Division is a complete organization for the development of process methods, mechanical design, equipment procurement, field erection and initial operation of plants and facilities for the oil, gasgasoline, chemical, power and allied industries.

#### IN MANUFACTURED PRODUCTS

Fluor's manufactured products include Aerator and Counterflo Cooling Towers, Fin-Fan Air-Cooled Heat Exchangers, Pulsation Dampeners, Mufflers, Gas Cleaners and related equipment. Second to none in quality or performance, Fluor products are in service in petroleum, chemical and power installations throughout the world.

You are invited to write for complete information on any or all phases of Fluor's operations.





ONE ANODE looks pretty much like another—until you try them. Then you find out what each is really worth—and the results are not always encouraging. That's why we, at IGE, take nothing for granted. IGE Graphite Anodes are made with uniform structure of controlled density, so that you never have to worry about the contaminating effects of rapid anode oxidation. They are carefully controlled for quality through every stage of manufacture—from processing the raw coke to final molding and graphitizing—to assure you anodes that will yield products of high purity. What's more, IGE Anodes are thoroughly process-tested. Before a new type of IGE Anode goes into production we put it into actual operation in the process for which it has been designed. We test it, we study it, we analyze its performance. That's why we can say with perfect confidence that IGE Anodes produce purer products... that they last longer. Be sure. Specify IGE!

# INTERNATIONAL GRAPHITE - LECTRODE DIVISION

#### SPEER CARBON COMPANY

St. Marys, Pennsylvania
Other Divisions: Jeffers Electronics • Speer Resistor

# international how how how

Building a refinery or chemical plant in a foreign country involves many considerations in addition to the basic functions of design and construction.

Foster Wheeler's worldwide experience gained from building more than 250 process units in over 40 foreign countries is saving its clients both time and money.

### FOSTER WHEELER CORPORATION

165 BROADWAY, NEW YORK 6, NEW YORK

process units
complete refineries
complete chemical plants





England

Construction continues at England's largest refinery.

at work

### around the world

Trinidad Scandinavia

Argentina

South Africa

Brozil Holla

Philippine Islands

> Australia Venezuela

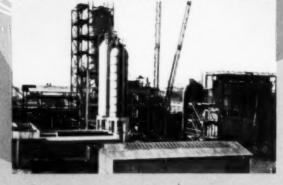
> > ond in

Canada

A recent completion at Edmonton.



France

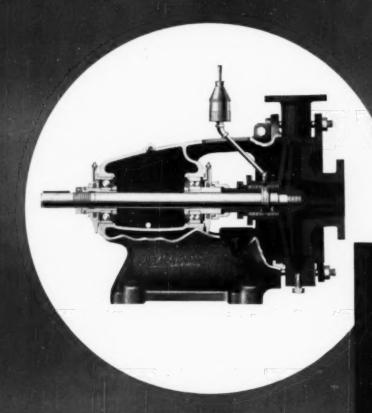


Catalytic cracking and other units under construction in France.

## FOSTER WHEELER

Complete engineering facilities at New York, Paris, London, St. Catharines, Ontario and Houston, Tex.

# For tough Chemical Service



DURCOPUMPS IN THESE ALLOYS

DURIRON DURICHLOR CHLORIMET 3

**DURIMET 20** 

**DURCO D-10M** MONEL METAL

**DURCO 18-8-5** 

INCONEL

DURCO 18-8-S-Mo NICKEL

CHLORIMET 2

NI-RESIST #2

Series R Durcopumps, designed and built to handle severe corrosives, are available in the alloys listed above as regular production items. For the details of construction and performance of industry's standard acid pumps, write for free Bulletins P/1 and 100B.



A product of THE DURIRON COMPANY, INC., DAYTON, OHIO



of many plastic materials.

Uniformly high quality GLC Graphite Anodes are doing their share to help the electrolytic industry meet the ever increasing civilian and defense demands for chlorine and caustic soda.

#### ELECTRODE DIVISION

Great Lakes Carbon Corporation

Niagara Falls, N. Y.



Morganton, N. C.

#### Graphite Anodes, Electrodes and Specialties -

Sales office: Niagara Falls, N. Y. Other offices: New York, N. Y., Chicago, Ill., Pittsburgh, Pa.

Sales Agents: J. B. Hayes, Birmingham, Ala., George O'Hara, Long Beach, Cal., Great Northern Carbon & Chemical Co. Ltd., Montreal, Canada,



BUFLOVAK Steam Jacketed Kettle, 2750 gals. Speeds the production of a high quality grease for a nationally-known company.

# Buflovak Kettles available in our Research Laboratories to test new processes . . . new products!

New and untried processes frequently present unexpected problems. The safest procedure is to process a quantity of the product and observe the results. Such facilities are available in the BUFLOVAK Research and Testing Laboratory. Results show positively what is needed for your processing. Kettles can then be designed and built to most economically and profitably fulfill your expected requirements.



Free! 48-PAGE COLOR BOOKLET

... So detailed it is literally a handbook on Heating ... Cooling ... Drying, etc. You <u>can</u> save time, cut costs, and make better products, by using BUFLOVAK Kettles in your processing. BUFLOVAK Kettles have proved to be a vital part in processing operations . . . and operations can be progressively performed in the same unit, thus speeding up production, lowering investment costs, and increasing profits.

BUFLOVAK Kettles perform a number of very basic operations: heating, cooling, mixing, extracting, reacting, distilling, evaporating, drying, and solvent recovery. Vacuum, atmospheric, or pressure operations can be provided.

Kettle sizes range from the one gallon laboratory size to massive units. Illustrated above is a 2750-gal. kettle.

Positive mixing and thorough cleaning of the heating surface is provided by eight distinct types of agitators with modifications to meet the individual need.

Yes, you will profit, as are so many varied industries today, by specifying BUFLOVAK Processing Kettles.

#### **BUFLOVAK EQUIPMENT**

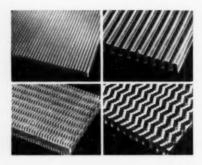
Division of Blaw-Knox

1567 FILLMORE AVE., BUFFALO 11, N.Y.

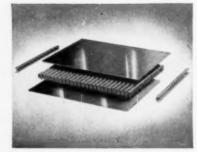
# Here's how Trane brazes aluminum to solve tricky heat transfer problems ...



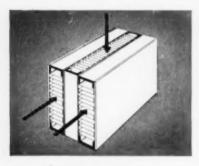
Corrugated fin surface for Trane Brazed Aluminum Exchangers is formed in special presses from aluminum brazing sheet. Thickness can range from .005 to .032 inch; fin height to .50 inch; spacing 4 to 18 fins per inch.



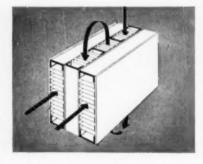
Many types of surface available. The brazed aluminum fins may be straight and continuous. Or they can be wavy, serrated or perforated to provide correct ratio of heat transfer to pressure drop.



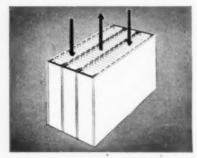
**Exploded view shows** component parts of a single passage. Fins, channels and parting sheets, all made from aluminum brazing sheet, become integrally bonded when assembled unit is submerged in a molten salt flux bath.



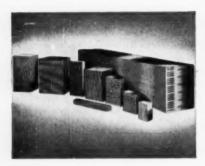
Cross-flow errangement has fins in adjacent passages running crosswise to each other. Trane Brazed Aluminum Surface can pack 450 square feet of heat transfer surface into one cubic foot of space.



Multi-pass arrangement, like the cross-flow type, has fins in adjacent passages running crosswise to each other. With this arrangement, however, alternate passages are constructed to produce multiple passes.



Counter-flow arrangement has fins in adjacent passages running parallel to each other. A wide variety of different types of corrugated fin sheets can be used to handle different fluids in the same exchanger.



A wide range of core sizes is available up to 106 inches in length. Either bolt-on or integrally welded headers can be provided. Individual cores can be welded together to form larger multicore units.



Design flexibility permits construction of units to handle practically any specification of heat transfer, pressure drop, volume, number and direction of passes. Some units handle as many as six different fluids simultaneously!

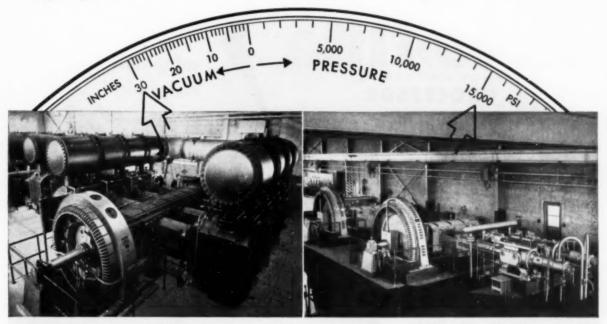
## TRANE

pioneers in the science of heat exchange

Wyee bave a tricky problem in heat transfer . . . Trane Brazed Aluminum Exchangers may be the answer. Contact your Trane Sales Office or write direct.

The Trane Company, La Crosse, Wis. • East, Mfg. Div., Scranton, Penn. • Trane Co. of Canada, Ltd., Toronto, 80 U.S. and 14 Canadian Offices

# any pressure or vacuum you want-



Three 2000-hp Ingersoll-Rand HHE Vacuum Pumps for exhausting testing chambers to simulate high altitude flying conditions. Piston displacement of 51,508 cfm is believed largest built to date in reciprocating equipment.

Two 900-hp Ingersoll-Rand 2-stage HHE Compressors boosting a mixture of hydrogen and nitrogen from 3500 to 15,000-psi pressure in the manufacture of synthetic ammonia. Two 2250-hp 4-stage units handle the primary compression to 3500 psi.

## from high vacuums to 15,000 psi pressure

Ingersoll-Rand Compressors meet industry's exacting needs with traditional I-R economy, dependability and low maintenance.

When a southern chemical corporation wanted to compress nitrogen and hydrogen to 15,000 psi in the production of synthetic ammonia, Ingersoll-Rand compressors were chosen for the job. When the aircraft industry needed big vacuum pumps to exhaust testing chambers in order to simulate high altitude flying conditions, again Ingersoll-Rand equipment was selected.

The installations pictured here are typical of the wide range of specialized services that I-R compressors are performing.

If you have a problem involving the compression or evacuation of air or gases, remember that for scores of years Ingersoll-Rand has been designing and building reciprocating, centrifugal, and steam-jet equipment—and combinations of these—to meet the most exacting requirements in all kinds of industries. Your I-R representative is well qualified to give you expert assistance, no matter what the gas, pressure, or process.



COMPRESSORS . PUMPS . AIR AND ELECTRICAL TOOLS . VACUUM EQUIPMENT . ROCK DRILLS . CONDENSERS . GAS AND DIESEL ENGINES

Technical data on the revolutionary new

# holo-flite

(HOLLOW-FLIGHT)

**PROCESSOR** 

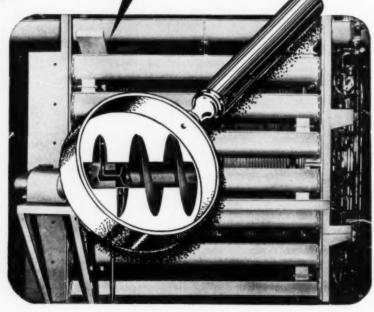
If you have processing operations where slurries, solids, pulps or pastes must be cooled or cooked, be sure to investigate the many unique advantages of the newly-developed Holo-Flite Processor before you install any heat-exchange equipment.

#### Hore's the HOLO-FLITE principle . . .

Two or more screw conveyors rotate slowly in a trough. The blades and shaft of each flight of conveyors are hollow, with provision for circulating the heat-transfer agent through them. The product to be cooled or cooked is moved along the trough, being constantly rotated into, around, over and under the conveyor screws as it moves.

Thus, a continuous thermal transfer takes place between the product and the heat-transfer fluid circulating in the blades. The product is cooled or cooked in continuous-flow without the "stop-and-go" losses of batching operations . . . and cooled products can be packaged directly from the Holo-Flite discharge—saving space, time and additional handling.

-the Continuous-Flow
Heat-Exchanger that is setting
new standards of
compactness!
adaptability!
simplicity!



THIS 6-TIER HOLO-FLITE cools 7 tons of cottonseed press cake per hour from 285° to 89°F. in a total floor space of only 28 sq. ft.

(Inset) Enlarged cutaway view of Holo-FLITE screw showing heat-transfer principle.

#### Here are typical HOLO-FLITE advantages

The Holo-Flite principle is so unique it is setting completely new standards of performance in many ways. For example...

\*Beg. T.M.

The HOLO-FLITE Saves Space—It requires as little as 1/5th the space of other units of comparable capacity because (1) it has far greater heat-transfer area per cubic foot of space... and (2) the flights can be "tiered" as high as desired to give maximum capacity in very small floor areas.

The HOLO-FLITE is Versatile— Processed product can be fluid, pulp or paste—granular, crystalline or powdered solid. Heattransfer fluid can be refrigerant, cooled or ambient water, steam, oil or any other desired fluid, at any normal temperature range.

The HOLO-FLITE Is Dust-Free—Its gentle action provides large heat-transfer action without dust and with negligible particle abrasion. Simplifies installations, assures higher quality product.

—It can easily be designed to handle virtually any capacity by (a) varying the diameter of the screws (7" to 16")...(b) varying the length of the screws (8 ft. to 20 ft.)...(c) varying

The HOLO-FLITE is Adaptable

varying the length of the screws (8 ft. to 20 ft.)...(c) varying the number of intermeshing screws per trough (2, 4, or 6)... and (d) varying the number of tiers stacked on top of one another (1 to 10, or more).



Main Offices: 1062 WEST NINTH STREET, LOS ANGELES 15, CALIFORNIA CHRYSLER BLDG., NEW YORK 17 \* 1 N. Le SALLE ST. BLDG., CHICAGO 2 1429 PEACHTREE ST. N.E., ATLANTA 5 \* HOBART BLDG., SAN FRANCISCO 4 PRECIPITATION CO. OF CANADA, LTD., DOMINGON SQ. BLDG., MONTREAL The Holo-Flite is in daily operation on such typical products as sand, cement, cottonseed cake, soybean meal, borax, salt, sugar, baby foods and many other equally-varied products.

What is your problem? Our engineers will be glad to assist you in making the most of Holo-Flite advantages. Write wire, or phone the office nearest you!

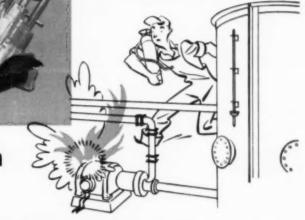
Wont More Facts? This 8 page booklet describing the HOLO-FLITE in greater detail will gladly be sent on request. No obligation, of course.



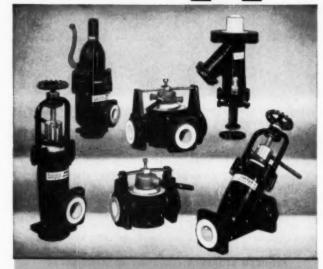
Minor Fire or Explosion?

YOUR

are SAFE with



# Lapp TUFCLAD



Y-Valves and Angle Valves (in sizes to 6"), safety valves, flush valves, plag cocks, are evaluable in Lapp solid percelain with TUPCLAD ermor. Also pipe and fittings (to 8") and a variety of special shapes.

Lapp

PROCESS EQUIPMENT

CHEMICAL PORCELAIN VALVES . PIPE . RASCHIG RINGS PULSAFEEDER CHEMICAL PROPORTIONING PUMPS

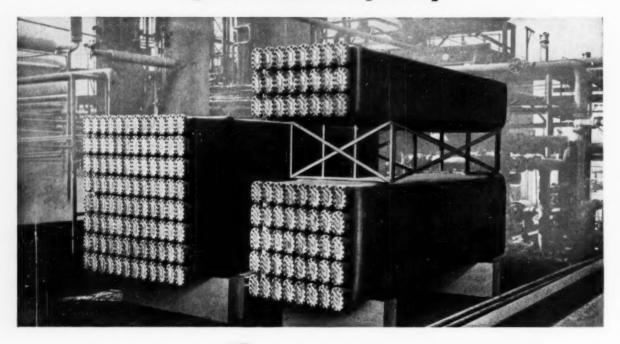
## ARMORED WITH FIBERGLASS-REINFORCED PLASTIC

Now there's mechanical security to go with the chemical purity and corrosion-resistance of solid Lapp Chemical Porcelain. TUFCLAD armor is the answer—multiple layers of strong Fiberglass fabric impregnated and bonded to the body with an Epoxide resin of high strength and chemical resistance. It serves as an insulator against thermal shock—a cushion to accidental impact. And it is itself tough and strong, able to hold operating pressures against gross leakage even if porcelain is cracked or broken. Provide this protection to your personnel, equipment and product.

WRITE for description and specifications. Lapp Insulator Co., Inc., Process Equipment Division, 521 Maple St., Le Roy, N. Y.

# Six Reasons Why

you should specify



### BROWN FINTUBE Sectional HEAT EXCHANGERS

FLEXIBILITY: If plant requirements change — and this is not uncommon—a "bank" of Brown Fintube heat exchanger sections can be disconnected and reassembled in different series-parallel arrangement easily and on short notice. "Bundle type" exchangers are not flexible. For them a change in duty usually involves designing — and waiting — for a whole new unit.

NO OBSOLESCENCE: Brown Fintube Sections never become obsolete. They can be used in one exchanger after another. Sections not in use serve as "standby" or parts, for other sections on stream.

REDUCED FOULING: Brown Fintube sections transfer more heat per lineal foot at lower surface temperatures. This minimizes coking. Also the longitudinal passages control the material flow eliminating eddies and reducing fouling.

EASY CLEANING: reduces maintenance costs. By manifolding just one extra parallel stream into an exchanger, the entire unit can be operated continuously—always clean—without ever coming off stream.

REDUCED STORES: Avoids tying up thousands of dollars in spare parts, housing and handling them.

PROMPT DELIVERY: Standardization permits economical assembly line manufacture from standardized parts — and prompt delivery.

If you heat — or cool — liquids or gases in your plant, you'll get a lot of ideas from our Bulletin No. 512. Send for a copy!



Brown FINTUBE CO. Elyria, Ohio

 Integral One-piece Fintubes; Sectional Heat Exchangers and Coolers; Vertical Heaters for Bulk Storage Tanks; Tank Suction Heaters; Pressure and Section Line Heaters; Process Tank Heaters; Fired Indirect Heaters and Special Types of Fintube Heaters and Coolers.

NEW YORK \* BOSTON \* PHILADELPHIA \* PITTSBURGH \* BUFFALO \* CLEVELAND \* CINCINNATI \* DETROIT \* CHICAGO \* ST. PAUL \* ST. LOUIS MEMPHIS \* BIRMINGHAM \* NEW ORLEANS \* SHREVEPORT \* TULSA \* HOUSTON \* DALLAS \* LOS ANGELES \* SAN FRANCISCO \* and ST. THOMAS, ONT.

### VACUUM

### FACTS

It's a FACT ...



... Kinney originated the rotating plunger vacuum pump... universally acclaimed for fast pump down and quick recovery.

It's a FACT ...



...Kinney pioneered the oil-sealed pumping system,

It's a FACT ...



... Kinney is the BIG LINE of mechanical vacuum pumps . . . more models, more sizes, more capacities to choose from.

It's a FACT ...



... Only Kinney offers in such a wide range both single stage and compound vacuum pumps — for creating and maintaining low absolute pressures alone or with diffusion pumps.

It's a FACT ...



... More vacuum processes depend on Kinney Vacuum Pumps than on any other make or type of pump.



trum Pumps can help in your low pressure processes — in laboratory, pilot plant, or production.

Find out for yourself how Kinney Vac-

Send coupon or write for details.

Kinney Manufacturing Co., Boston 30, Mass. Representatives in New York, Chicago, Detroit, Cleveland, Atlanta, Philadelphia, Pittsburgh, Johnstown (Pa.), Los Angeles, Charleston (W. Ve.), Mouston, New Orleans, Son Francisco, Seattle and fareign countries.

K	ı	NI	N	E	Y	M	A	N	11	F	A	C	T	11	R	1	N	G	- (		3
		1.0	N			240	~	2.0	w		~	•		•	80.		1.0	9	•	m a	•

3546 Washington St., Boston 30, Mass.

Please send new Bulletin V-51B. Our vacuum problem involves:

- Vacuum drying
- Vacuum coating
- Vacuum metallurgy

- Vacuum impregnating
- Vacuum distillation
- Vacuum research

Compan

Address

State



SUBSIDIARY OF THE NEW YORK AIR BRAKE CO.



special needs of pilot plant or laboratory operations requiring continuous small quantity feeds with "absolute" accuracy, independent of viscosity or system pressure variations. Here is a compact, accurate charging system or test unit which gives uniform, reproducible conditions and quick, accurate prediction of the full scale end result.

A precision ground plunger is forced into the fluid-filled cylinder at a readily adjustable, predetermined rate. Since the fluid is forced out of the cylinder by the uniform progress of the screwdriven plunger, there can be no fluid loss due to valve action or changes in plunger speed. The cylinder may be jacketed or insulated to maintain uniform conditions. The standard Micro-Feeder is available in models for feeding from 1.0 cc to 800 cc per hour and for maximum discharge pressures up to 2000 psig. Special Micro-Feeders can be furnished for other conditions. Ask for recommendations and Bulletin SM-3005-2.

### Micro-Feeder Applications include . . .

- 1. Catalyst Testing
- 2. Additive Injection
- 3. Carburetion of Fuels
- 4. Explosive Mixture Analysis
- 5. Calibrating Instruments
- 6. Porosity Determination
- 7. Laboratory Titration
- 8. Injection of Vitamin Concentrates
- 9. Toxicity Measurements

# % PROPORTIONEERS, INC.% (%)

Write to %PROPORTIONEERS, INC.%, 419 Harris Ave., Providence 1, R. I.

Technical service representatives in principal cities of the United States, Canada, Mexico and other foreign countries.

## Opinion and comment

#### **BUSINESS RECESSION IN 1954?**

of infrequently of late we see comments in the press to the effect that we are likely to experience a business recession in 1954 after defense spending diminishes. On one occasion at least a reputable magazine printed a rumor that the new administration might reduce the rate of defense spending in 1953 in order to spread out the total expenditure over a longer period of time for the purpose of softening the business recession.

Such statements reflect defeatism. Has our economy become dependent for prosperity upon the production of tools of destruction? The answer is definitely No! The prosperity created by producing tools of destruction is artificial. In the past it has been attained in large part by mortgaging our future and that of our descendants.

A far higher level of prosperity can be had by producing tools of production after the manufacture of tools of destruction becomes unimportant.

There would be no excuse for an economic recession after this production drops to a nominal level. Of course, if the demand for tools of production is insufficient, we will have a business recession when defense spending drops off rapidly. The primary reason for this is that a large part of the capacity of the capital goods industries is occupied at present with the production of war goods. When this high rate of production drops to a nominal magnitude, these industries will be dependent upon the demand for tools of production to maintain full employment. If this demand is at a low level, the capital goods industries will suffer an economic depression.

Since the capital goods industries employ about one third of the Nation's industrial labor, a serious loss of their business certainly would be felt as an economic recession by the entire Nation. The Nation has never enjoyed general prosperity unless the capital goods industries were operating at high capacity. We learned during 1933-1942 that general prosperity and full employment could not be had until the capital goods industries enjoyed full employment. Unfortunately this was not attained until 1942 when the production of tools of destruction brought it about.

But why should we have a business recession in 1954 when it is within our power to provide a smooth transition from the production of tools of destruction to the creation of tools of production? This Nation is definitely not dependent upon war goods production to keep the capital goods industries at full capacity. There is need for replacement of obsolete tools of production as well as for the creation of entirely new industries which will raise our living standard. We have only to remove the serious barriers which now lie in the path of private investment in new tools of production. The most important of these barriers could be removed in short order

by Congress merely by eliminating all the limitations now imposed on rates of amortization for new tools of production in applying our Federal tax laws.

Investments in new tools of production are legitimate business costs. Furthermore, no profit is made on such investments until they have paid for themselves. Therefore, the investor should be permitted to write off his books the cost of tools of production as rapidly as these tools will pay for themselves. If the investor were permitted to get his money back before any book profits or taxes were taken, his risk would be reduced to the minimum. This would provide new and large sources of risk capital not now available.

But as the tax laws now are applied, the rate at which the cost of industrial tools of production can be charged off against income is limited on the average to less than 4% a year, which is equivalent to a period of more than twenty-five years before the investor is able to charge off the cost. This might be reasonable for depreciation, but it is far from reasonable for amortization. It appears that there may be considerable confusion between the purpose of depreciation and the purpose of amortization.

If Congress would remove all limitations on amortization rates, it would not affect the total taxes collected from a given tool of production over its useful life, other factors being equal. On the other hand, because of new industries that would be created under the more favorable atmosphere, the taxes collected from industry as a whole, at the same tax rate, would be greater. The effect of removing all limitations on amortization rates would be merely to postpone the collection of income taxes from a tool of production until the tool had paid for itself. It is unjust to impose limits on amortization rates so that taxable book profits must be shown before a tool of production has paid for itself.

If Congress removed the limitations on amortization rates for new tools of production, it would stimulate such a demand for capital goods that it would be beyond the capacity of industry to fill the orders. Furthermore, we would enjoy real prosperity for a change. Small business would be benefited even more than the large well-financed business. Since Congress goes to great lengths to assist small business, it would seem that a tax law which seriously hinders the progress of small business would be corrected.

Congress should be advised on this and the engineering profession is well qualified to render this advice. The Engineers Joint Council is the proper organization of the engineering profession to do this job in my opinion, and, I hope E.J.C. will, at an early date, shoulder this important responsibility of the engineering profession to the Nation.

C. G. KIRKBRIDE, Vice-President, A.I.Ch.E.

TYGON TUBING — as used in an automatic picture taking machine. Here the clarity, flexibility, and resistance of TYGON to photographic chemicals has greatly increased service life, simplified operation, and minimized maintenance as compared to that obtained with rubber tubing.

#### TYGON PAINT



quickly applied, fast drying protection against corrosive fumes and spillage.

#### TYGON TANK



long lasting, heavy duty sheet TYGON to withstand virtually all chemicals.

#### MOLDED TYGON



accurate, durable parts and fittings of outstanding chemical resistance for all types of equipment.

# PROBLEMS

#### **EASILY SOLVED WITH**

# TYCON

Every day, tough piping problems — big and small — are being solved with versatile, plastic TYGON TUBING. Designers and engineers, throughout industry, are finding TYGON the quick, easy, positive answer to tricky transmission jobs involving liquids, gases, or semi-solids.

TYGON Tubing not only resists acids, alkalies, oils, greases, certain solvents, and water — but is glass-clear and fully flexible. TYGON also is strong, smooth-surfaced, abrasion-resistant, light in weight, and non-oxidizing. Certain formulations are completely non-toxic.

TYGON's excellent chemical resistance permits its use with virtually any corrosive. Its clarity permits full solution visibility and control. Its flexibility permits the most intricate use without kinking. Its smooth surfaces give maximum flow, easy cleaning, and free draining. Its non-toxicity assures complete safety in food, beverage or medical applications.

TYGON Tubing is made in continuous lengths and a number of stock sizes ranging from ½"
ID to 2" ID. There are six standard formulations available in clear or glossy black which exhibit a range of physical, electrical, and chemical properties. Braided jacket reinforcement of stainless steel, Saran, or cotton is available and suggested where high constant pressures are encountered.

Special compounds and sizes — including rigid tubing — to meet specific requirements can be made where volume warrants.

Write, today, for more information and technical assistance on the use of TYGON Tubing. Ask for Bulletin-77. Ask also about the other forms of versatile TYGON that can help you combat corrosion.

#### U. S. STONEWARE

AKRON 9, OHIO



PLASTICS AND SYNTHETICS DIVISION



### **Grinding and Crushing**

This series of papers on crushing and grinding begins with the theory of this unit operation and then swings over to applications and the practical solutions offered by manufacturers of grinding machinery.

The articles are presented as a unit in one issue in order to furnish a brief, convenient review of grinding from the basic engineering principles to current industrial practices, and are adapted from a recent symposium on the subject held by the New Jersey Section.



E. L. Piret

Edgar L. Piret is professor of chemical engineering at the University of Minnesota and a consultant to industry. In 1950-51 he was a Fulbright research professor at the Universities of Nancy and Paris, and in 1951 he was awarded the Friedel medal by the University of Paris. After receiving the Ph.D. from the University of Minnesota in 1937, he became a member of the chemical engineering department, from which he took a leave of absence in 1943 to join the Minnesota Mining and Manufacturing Co. He was in charge of the chemical engineering division when he resigned to return to the university.



H. W. Erickson

Henry W. Erickson is regional mining and chemical specialist of the Allis-Chalmers Manufacturing Co., which he first joined in 1929. During the war he was chief of resources, mining division, War Production Board, after serving in the Marine Corps. Mr. Erickson's experience prior to his joining Allis-Chalmers included five years in Mexico and Chile for the American Smelting & Refining Co. and Braden Copper Co. He recently headed a symposium on ore dressing at the Industrial College of the Armed Forces, Washington, D. C. A graduate of Massachusetts Institute of Technology in 1920, Mr. Erickson is a licensed professional engineer.



J. H. Foote

J. Howard Foote, secretary and sales manager, Pulverizing Machinery Co., Summit, N. J., has been in the grinding and crushing field all his business life. After studying engineering at Rutgers University, he served his apprenticeship in the grinding room of his present company and successively thereafter became head of the laboratory, sales engineer, and finally sales manager. During the war he supervised a subsidiary plant established by Pulverizing Machinery to grind magnesium for Navy use.



### Fundamental Aspects of Grinding

Edgar L. Piret University of Minnesota, Minneapolis, Minnesota

Chemical engineers, often concerned with the practical aspects of crushing operations, remember having only cursorily studied the operation in college. In fact, crushing and grinding to most engineering students was, and unfortunately still is, dubiously outstanding among the unit operations for its lack of a theoretical and quantitative base. Perhaps they also remember that the material offered was mostly descriptive of the types of machines available and of their usual fields of application, that special kinds of graph paper were used on which it was convenient to plot sizedistribution curves, and that a controversy existed between the two supposedly basic theories of crushing. Indeed, if a power requirement was calculated by use of Kick's or Rittinger's equations, widely differing results were obtained, and the matter of deciding on the correct method was abruptly left in the air. It was not a very satisfying experience.

Nowadays, several empirical grindability indexes are available to answer, roughly, some of the practicing engineer's questions. Moreover, during the last decade or two inventive minds have produced some new and better machines. But there have been but few important additions to our meager basic understanding of the mechanism or of the quantitative aspects of the crushing process itself. This paper will treat some of these and indicate possible applications. First, however, some methods of measurement, plotting, and correlating crushing data will be briefly reviewed.

#### **Area Measurements**

Today, besides the usual screening, turbidimetry, and sedimentation methods, there are two relatively recent methods of measuring the surface area of the product of a crushing operation. They are, for many purposes, clearly an advance over previously available methods, which were often dependent on the dubious accuracy of an assumed shape factor.

The gas-adsorption method of Brunauer, Emmett, and Teller requires complex apparatus and is tedious to perform, but it does measure quite well for many materials the total surface exposed by a crushing operation. It is based on the accurate measurement of the volume of a gas such as nitrogen, krypton, or ethane, or of larger molecules adsorbed usually at low pressures on a sample of the solid product. Knowing the parking area of the adsorbed molecules, one can then calculate, with the aid of adsorption equations, the total area of the particles. This method measures, on a molecular scale, the area in fissures, pores, etc., as well as that of the external surface of the particles.

The permeability method of area measurement, on the other hand, is not so time-consuming, and the apparatus needed is relatively simple. A gas or a liquid is passed through a bed of crushed particles, and from the pressure drop, rate of flow, and volume and porosity of the bed, the total area of the particles can be calculated from equations which are related to the Kozeny modification of the Poiseuille equation for laminar flow. The same equations were first applied by B. F. Ruth to filtration calculations. The permeability method however will not measure the area of deep fissures, closed pores, etc., as does the gasadsorption method. But, as can be shown by checks on even irregular dense particles of known area, it does measure. and rather accurately, the surface area of the particles which is available to the fluid flowing in laminar flow. Arnell and others have extended the method to exceedingly fine particles (2).

As expected, the area measured by the adsorbed-gas molecules will be higher than that measured by the permeability method. It has been shown that the ratio of these areas will be near 2 for a non-porous material such as quartz, glass, magnetite, etc., while it can reach almost any value for a material which has a large number of inner pores. In a crushed hematite sample, for example, the area available to krypton adsorption

was found to be 128,000 sq.cm./g. while only 2060 sq.cm./g. was measured by the permeability method. This is an area ratio of 62. Indeed, the area of a crushed particle is not an absolute quantity but is best defined in terms of the method and the scale of measurement. To illustrate, a profilometer will lead to a different area calculation than will a meter stick; yet both are correct.

The point to be kept in mind is that the method of area measurement to be selected depends on the purpose of the measurement and on the nature of the operations to which the crushed product is subsequently to be exposed. For an adsorption process, such as might occur in a flotation treatment, the most significant area will be the total area available to the particular size of the diffusing molecules used and will include the area in the pores and fissures. On the other hand, for a simple dissolution process, probably only the area available to the flowing fluid is rapidly being dissolved. Hence to the first problem the gas-adsorption technique should be applied. while the permeability method is better suited to measure particles to be used in a dissolution process.

There are other methods, of course, for measuring the surface areas of fine particles obtained from crushing operations. For example, the area of quartz particles has been calculated from the rate of dissolution in hydrofluoric acid. Obviously, such a method is limited to homogeneous materials for which a suitable dissolving agent can be found. Other materials may have specific properties that may make their surface determinations convenient. Figure 1 shows the relationship between the increase in coercive force of samples of crushed magnetite plotted against the new surface produced in the impact crushing of this material in a drop-weight crusher. The surface in this case was measured by the permeability method. Since coercive force can be rapidly and easily measured, magnetite has a special advantage as a material to be used in research investigations of crushing phenomena.

#### **Screen Analyses**

The size distribution of a crushed product is also important and is most commonly measured on a series of sieves. There are several choices as to methods of plotting the size distribution, and one method may, for certain purposes, be more revealing than others. If the logarithm of the cumulative percentage passing is plotted against the logarithm of the mesh size, an inclined straight line will be obtained over much of the range of fine sizes for the products of hammer mills and, with certain limitations, for the products of ball and rod mills. In Figure 2, the equation of the top line is of the form  $y = Ax^n$ , where x is the size of the sieve aperture. y equals the corresponding cumulative percentage by weight of material passing through the sieve mesh, and A and n are constants. When the slope, n, of the curve is unity, the surface areas of each of the different-sized fractions are equal. Gaudin and Hukki (7) found that the size distribution obtained by the fracture of a single crystal is such that, over a very wide range, the new surface on each grade is the same. In most cases, however, the finer size fractions in multiple-particle crushing have more surface area than the coarser fractions and the slope is less than unity, with an

average of about 0.7 for wet closedcircuit grinding and higher for crushed products. The lower curve in Figure 2 is obtained by plotting the logarithm of the percentage weight of material retained on each successive screen against the logarithm of the sieve size or, alternately, the sieve serial number. The straight-line portion of the curve is represented by an equation of the form  $\Delta y = Kx^n$  where n is the same as the slope in the previous equation. A straight line is obtained on this type of plot whether the cumulative grading curve follows a relation expressed by  $y = Ax^n$  or one based upon  $y = Ax^n + C$ .

A noncumulative grading curve which shows the weight of material that is retained on each of a series of sieves is best obtained by graphical differentiation of a simple cumulative grading curve, where the percentage passing is plotted against the mesh size on arithmetic scales. This type of plot, as indicated by Ratcliffe (16), may be more revealing of the process occurring in the machine than are the logarithmic plots shown previously. For example, Figure 3 is a noncumulative grading curve of the product of a jaw crusher which was fed with clean lump limestone. In such a crusher the coarse particles are subjected to a sizing influence in passing

through the narrowest portion of the crusher. This can occur in a jaw, gyratory, or roll crusher, and, as can be seen on the right of the figure, the size distribution follows a Gaussian pattern.

The fine particles are produced partially in this Gaussian manner and also, as can be seen from the shape of the curve on the left, by processes of free fracture, similar to those occurring in a hammer mill, where fracture is due to impact, splintering, and spontaneous refracturing of the material. A hammer mill, on this same clean limestone, does not have the size distribution indicated by the Gaussian distribution of the jawcrusher curves but will simply follow the form of the curve on the left in Figure 3. Obviously, since several types of fracturing processes are occurring in the jaw crusher, for example, it is hardly reasonable to expect a single equation to apply to such a machine. The separate actions must be appreciated and analyzed individually if progress is to be made. Thus, by preparing plots of these various types, one can learn something of the operation of the crushing machine and its characteristic product.

Plotting size distribution on log probability paper often results in straight lines, from which, as has been shown by Hatch and Choate (9), the statistical

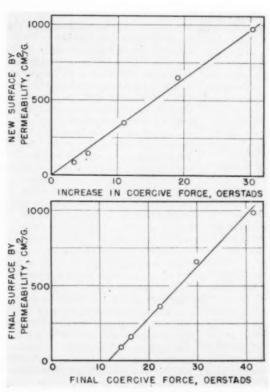
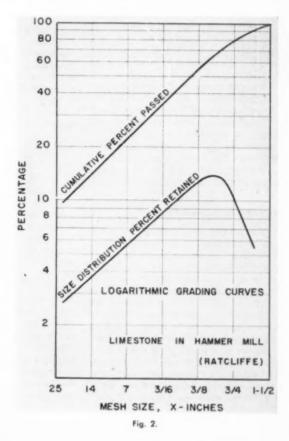


Fig. 1. Coercive force—area relations for 10/14 mesh Ural magnetite.



Vol. 49, No. 2

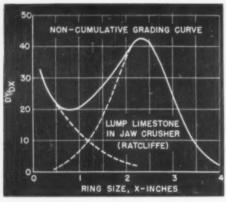


Fig. 3

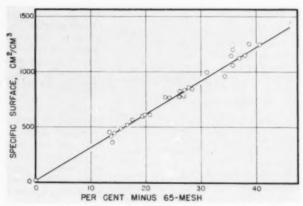


Fig. 4. Specific surface of entire sample of crushed 0.25-  $\times$  0.9-cm. squares of window glass vs. screen analysis.

constants of the distribution are readily obtained.

One may wish, for simplicity and convenience, to express the approximate particle size of a feed or of a crushed product by a single number. For this purpose, it has been suggested that the size in inches or in microns of the screen opening through which 80% of the material passes be used to designate briefly a feed or product size. In the same manner, the total surface area of a crushed product will express its size by one number. Obviously, such simple designations, while useful, have real limitations. As another example of simplification, Figure 4 shows that, for the case of a laboratory drop-weight crusher, the total new surface produced in crushing 4- to 8-mesh glass by impact is simply related to the percentage of the crushed product passing 65 mesh. Similar, slightly curved lines of per cent passing 65 mesh vs. total new surface were recently obtained in the author's laboratory for crushed quartz, taconite, magnetite, and hematite. The permeability method was used to measure the areas of the feed and of the product in these experiments.

#### **Energy Requirements**

The product of a crushing operation can be measured, as has just been seen, in terms of the new area produced or of size distribution. However, the question arises as to how much power is required to produce the crushed material. This power, as well as the area produced and size distribution, can be expected to vary with the nature of the material and, as illustrated by the case of the jaw crusher, with the type of crushing device used. To answer this question, various empirical grindability indexes have been proposed, and apparently these are useful for some power-estimating purposes. Most of them are based upon some variation of the concept that the number of revolutions of a specified laboratory ball or rod mill which are needed to produce a stated percentage of the product passing through, let us say, 200 mesh will be a measure of the grindability of the material. Or the index may be based on the weight of undersize obtained after a specified cycle of operations including recirculation on a standardized laboratory machine. However, because of the deficiencies of these grindability indexes for the prediction and accurate comparison of crushing and grinding installations, none of these indexes have been accepted as a standard.

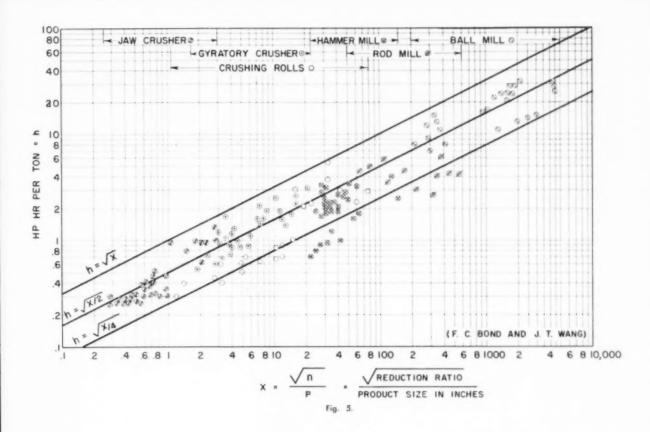
Figure 5 is an empirical energy chart presented by Bond and Wang (5) which shows the energy required to crush and grind many different materials in the various machines indicated at the top of the chart. The lower straight line on the plot is for soft material, while the second is for an average ore, and the top line is for a hard stone. The relation is

hp.-hr./ton = 
$$k\sqrt{\frac{n^{\frac{1}{2}}}{P}}$$

where the reduction ratio, n, is defined as the size of opening which 80% of the feed passes, divided by the size of opening which 80% of the product passes. This 80% passing product size, expressed in inches, is identified by the letter P. The value of k is equal to 0.25 for soft, 0.50 for medium, and 1.0 for hard materials. This ratio of 4 to 1 in power requirements is not in disagreement with measurements of the energy requirement per unit of new area produced in a laboratory drop-weight crusher. F. C. Bond (4) has recently proposed another work index to permit closer predictions and more accurate comparisons of crushing and grinding installations than have heretofore been possible. It is obtained from an equation for work input which is intermediate between that of Rittinger and that of Kick. Today prediction of energy requirements is largely dependent on such semiempirical methods.

#### Laboratory Results and Correlations

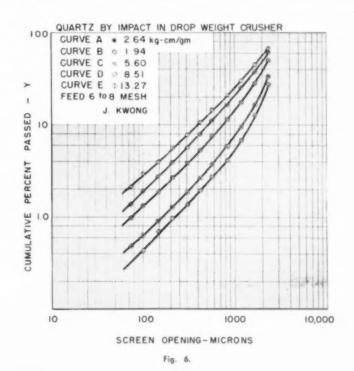
Most investigators interested in studying the theory of crushing and in developing a rational basis for engineering evaluations have used simplified laboratory machines in order to obtain as accurate and as reproducible measurements as possible of the energy input and the product formed. Fahrenwald, et al. (6), immersed a small ball mill in a calorimeter, and, by measuring the rise in temperature of the water flowing through, found that 75 to 94% of the energy input to the machine appeared as heat in the water. Various dropweight and pendulum crushers have been used, particularly for impact crushing tests. In the author's laboratory a simple crushing device has been used consisting of a steel mortar with a close-fitting plunger. A bed of broken particles of the material to be crushed or, in other experiments, a single particle is placed in the mortar cavity, and pressure is applied through the plunger, either in slow compression with a hydraulic press or in impact by dropping a steel ball of known weight a measured distance to the plunger top (12, 1, 11, and 3). Corrections are applied for energy losses to the mortar assembly in order to find the net energy input to the crushed material. Surface determinations by gas adsorption and/or permeability, as well as some screen analyses, are made on the initial and final particles. In Figure 6 several logarithmic cumulative percentage passing curves for 6- to 8-mesh quartz crushed in the drop-weight crusher have been plotted. The highest curve is for the greatest energy input. Over the fine range, the lines are straight



and can be represented by equations of the form  $y = Ax^n$ . The slope n is  $0.95 \pm 0.05$  and thus does not change much with net energy input. The value of A, however, increases linearly with the net energy input to the material, as shown in Figure 7. Thus the vertical displacements of the straight lines are directly proportional to the energy input, and the relation between energy input and size distribution is defined. These are useful equations which have not appeared in the literature.

The simple relation between the measured total area of the crushed product and the size through which 65% by weight of the material passes has arready been noted, as have the practically linear relations between the energy input and the new surface produced for brittle materials such as quartz, glass, fluorite, calcite, labradorite, sphalerite, and apatite, crushed by impact in a drop-weight crusher. The crushing resistance, say in kilogram-centimeters per square centimeter, is the slope of this line. While the initial particles were uniform in size, about 8- to 14-mesh, on repeated blows, the crushing process was taking place on the logarithmic size distribution corresponding to the lower curves of Figure 6. Thus the energy versus surface linearity is evidently not limited to the crushing of uniformly sized feeds. Similar straight lines have now been obtained for other brittle solids. Recently, Swedish workers (14) who used a ball mill to crush quartz also measured the new surface produced by the air compression of beds of many particles of

permeability method and obtained the results represented by Figure 8. The straight line in Figure 9 is for the slow



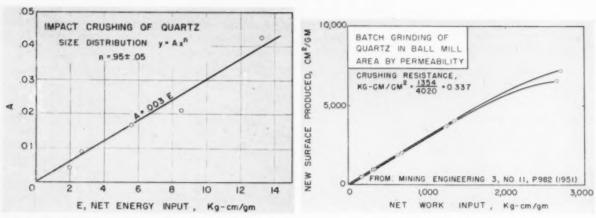


Fig. 7. Relation of energy input to A in the size-distribution equation.

Fig. 8.

quartz (3, 11). Over the same very wide range of energy input, quartz crushed by impact will show some curvature.

Many materials are not brittle but show plastic flow when stressed. Such a material is sodium chloride, which when crushed by impact will show a pronounced curvature toward the energy axis. X-ray analysis brings out clearly that the sodium chloride has been plastically deformed by the crushing and that, therefore, some energy has been absorbed internally (1). That temperature, even over the wide range of -58° to +400° C., has but a minor effect on the crushing resistance of glass is shown in Figure 10.

While the hardness of a material, as expressed by the Moh number, is hardly a fundamental property against which one might like to develop a relation between crushing resistance and the material being crushed, it is perhaps a convenient one and one can see from Figure 11 that a linear relation does seem to exist between the crushing resistances expressed in energy input per unit of new surface produced and the Moh hardness. The density term, inserted in the abscissa of this particular plot, does not have a large effect other than to bring the points, particularly for various grades of taconite, somewhat closer to falling on the single straight line. This can be verified by plotting the crushing resistance simply against the Moh hardness.

Figure 11 shows that for the homogeneous, brittle materials tested, the resistance to crushing, that is, the total new surface produced per unit input of energy, does not vary more than fourfold over the entire range of hardness tested, which ran from calcite at a hardness of 3, up to topaz of a hardness in agreement with the lines drawn by Bond and Wang, based on their experience with industrial operations on homogeneous and heterogeneous solids. For

all the materials listed on Figure 11, the new surface varies linearly over an appreciable range with energy input.

Such data and correlations can lead experienced people to develop more quantitative and industrially useful approaches to the measure and prediction of the performance of present and projected industrial mills.

# The Future

#### FACTUAL ASPECTS OF THE PROBLEM

Interest in this old unit operation of

crushing has lately tended to be directed toward even more basic aspects than the energy relations with the end products of the process such as have just been outlined. One would like to learn something of the mechanism of crushing, indeed of the fracture process itself.

Some features of the crushing process apparently are orderly in gross and yet are complex in detail. Consider the straight line of Figure 9, which was obtained by the slow compression of a bed of 10- to 14-mesh quartz placed in the

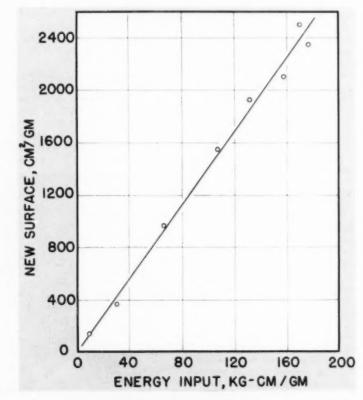


Fig. 9. Slow compression of quartz.

cavity of the crusher described. The new surface produced was measured by gas adsorption. The mortar and plunger were compressed between the jaws of a hydraulic press, and, from measurements taken of the force acting on the piston and its movement, the work input was easily calculated with minor corrections for the deformation of the steel. There are few sources of serious errors in such a procedure, and the results are probably quite trustworthy.

Unless a fortunate averaging takes place, such a simple straight-line relation over a wide range of conditions would seem to indicate that perhaps energy input to crushing is transformed to new surface energy by a relatively simple process. Most of the energy, however, goes to heat and only a very small fraction to new surface energy. Or the straight line can indicate that the overall process is controlled by relatively simple and uniform steps. Yet consider for a moment the complexity of the series of many parallel and consecutive fractures actually occurring when a bed of compressed particles is being crushed in even the relatively simple drop-weight crusher described. The forces, applied throughout the bed of particles, are not simply and uniformly distributed, but are concentrated at protruding points of contact, so that shear as well as compressive stresses enter; and, as one particle fractures, its strain energy is released and probably finally lost in the form of heat. Then the particles are recompressed by the advancing bed, and the process repeats itself. And especially note that the energy required to produce a square centimeter of new surface in such a bed is from 50 to 1000 times higher than the theoretical amount as calculated from bond energies (1 and 3). Despite the fact that only about 0.1 to 1.5% of the total energy input appears as surface energy, and that one could expect a haphazard and probably complex relation between energy and surface, it is seen experimentally that the new surface actually increases simply and indeed practically linearly with the energy input, just as though somehow all of that energy were concerned in the area-forming process, as it probably is. Also, as has been shown in a ball mill where complex impact, compression, shear, and attrition processes enter, the new area produced is still proportional over a wide range to the energy input. The machine efficiency can, of course, be expected to affect the proportionality factor.

Single pieces of polished quartz, when compressed slowly, will suddenly explode into a large number of small particles (15). Size of particles produced from a single crystal depends on the energy level at which fracture occurs

(3). The higher the pressure at fracture, the finer the particles produced. And the efficiency is many times lower at high energy levels than it is when the particle breaks at low pressures.

The pressure at which the initial fracture of a slowly compressed single polished-quartz particle occurs will vary widely from specimen to specimen, depending partly on contact conditions with the compressing surfaces and the presence of minor flaws and cracks in the specimen. Yet the fracturing by impact of a piece of quartz produces a surprisingly uniform distribution of fine particles. It has been shown that the particle-size distribution of single crystals fractured by impact is such that the new surfaces are equal on each grade of a geometric sequence of sieve sizes such as the  $\sqrt{2}$  scale (7). By calculation, repartition of the initial particle into fractions of equal areas per mesh

extends down to near the unit crystal size. Hence again some aspects of the fracture process are regular over extremely wide ranges.

One could say that large flaws can explain the initial fracture, but that from then on the process is on its own. The initiation period of fracture propagation, with branching, and termination of advancing cracks at surfaces reminds one of the initiation, propagation, branching chain and termination reactions of the chemical laboratory. Stress waves, released by an initial fracture pulse, can interfere to produce highly stressed regions where new fractures initiate. As shown by Irwin and coworkers (10), cracks start slowly until the rate of energy flowing into the crack from the released stress field becomes greater than the work required for new area formation. Then the crack becomes unstable and accelerates spon-

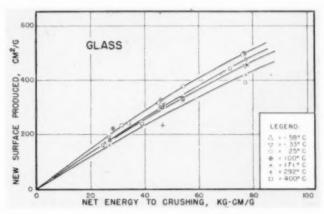


Fig. 10. Effect of temperature on the crushing of glass.

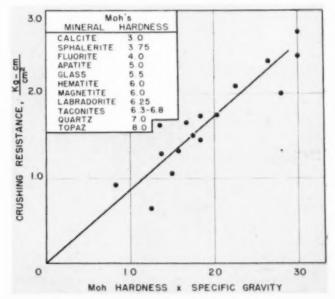


Fig. 11. An empirical correlation.

taneously until, if sufficient energy is available to it, its velocity approaches that of sound, and branching occurs. This branching forms one surface of a new particle. While the successive steps of the crushing process appear to be exceedingly complex, the over-all controlling process may essentially be quite simple. Yet today this relation has not been reported in the literature. The analogy of the thought of a rate-controlling step and a corresponding activation energy is found in the modern nucleation theory and in the theory of rate processes, and it is proposed that this attack be used on the crushing process (18).

It might be added at this point that while it takes 50 to 1000 times the theoretically calculated energy for the production of new surface area by crushing, materials such as steel, glass, or sodium chloride in ordinary tension or compression tests break very easily, in fact, when the forces applied are only of the order of 1/500 of the theoretical values, which are also calculated on the basis of bond energy. The factor of ignorance in the field of the cohesive strengths of materials to tensile and crushing tests is, then, of the order of 105. The proposal that the tensile failures are easily explained by the presence of the permanent flaws in the material has always been attacked. Thermalfluctuation theory such as is applicable in nucleation processes seems a more likely approach. Here incipient cracks are conceived to be always forming and disappearing in the solid, and, for the conditions of unstable equilibrium, the free energy relations can be written to supply the value of the activation energy of the rate process. This fracture initiation step and not the strength of all the atomic bonds acting simultaneously would control the process of fracture in a single particle. Reflected energy-wave concentrations would determine the location of fracture. Obviously there is ample opportunity for work to be done in this field.

Basic research in crushing has much in common with that of strength of materials; with fracture studies on metals, glass, liquids, and plastics; and, as has been proposed, with the theory of reaction kinetics, nucleation, and rate processes. It is quite possible that basic studies of the fracture process in crushing may furnish key ideas or data applicable to the tensile and compressive strengths of many important engineering materials. Indeed, the ease of studying energy, surface, and particle-size relations by crushing experiments on multiple and on single particles offers a new and hitherto unused tool to study the fundamental process of fracture. A study of the literature on tensile and

compressive strength of solid materials leaves one with the impression that knowledge of basic mechanisms in those fields is not much ahead of that in the art of crushing.

## POSSIBILITIES OF A RATE THEORY

It has been suggested that many of the phenomena observed in crushing and in tensile- or compressive-strength experiments are analogous to those observed in nucleation processes and in kinetic studies of chemical reactions. This may be surprising because one is perhaps not accustomed to thinking of crushing as a rate process, that is, as a process in which time is an important variable. In the following, consider the reciprocal of the time of stress before fracture occurs to be equal to the initial rate. Time, and hence rate, it will be shown, does indeed enter into the fracture process, and therein may very well be a basic variable of importance which should be studied if the fundamental process of fracture and crushing is to be understood. It is well established experimentally that in tensile tests of brittle materials, the resistance to fracture of a material is a function of time. However, very wide ranges of time must usually be studied to, say, double or triple the tensile strength. For a steel, plastic flow may be initiated in a matter of 0.001 to 10 sec., while for nylon fiber one may work in terms of 1 to 1000 sec., depending on the forces applied. The forms of the force, delayed time curves, however, are very similar for these materials.

It is clear, of course, that temperature enters into the fracture process, since it has been observed that at low temperatures many materials become quite brittle and break readily on impact; it has also been observed that while a material may flow in a plastic manner when subjected to a slowly acting force, it can break in a brittle manner if a fast acting force or impact is used. Time and temperature, therefore, enter into fracture processes, although not always with comparable importance. As in reaction kinetics, their importance depends on the activation energy of the controlling step, and so in some ranges their effect will apparently almost completely disappear. Hence, the failure of a wide variety of materials other than minerals needs to be studied from this viewpoint: these should include plastics and metals.

Rate of loading is also a factor in crushing. For example, crushing single particles by impact in a drop-weight crusher demonstrates that the energy required to produce 1000 new sq.cm. of surface is about three times greater than the energy required to produce that same surface in slow compression. Also, the slow compression of a bed of particles of quartz produces, for the same energy

input, more surface than if impact is used. The times of impact used in these experiments are perhaps of the order of microseconds, while the times for the slow compression may run from a second or so to several minutes. It has also been observed in the laboratory that a time interval occurs between the moment of compression to the maximum applied load and the moment of fracture of single polished specimens of quartz.

The quantitative experiments performed to date on the effect of time in crushing are very few, and it will be necessary to borrow extensively experiments and ideas from related fields to make the points. For example, the time required to rupture a heat-resisting alloy at constant temperature and constant tensile load is logarithmically related to the stress, and the entropies and heats of activation can be computed for the process (13). Activation energies for the tensile fracture of glass rods have also been computed, based upon force and delay time before fracture data (17). It is also interesting to note from a chemical reaction kinetics viewpoint that the time of stress before the fracture of porcelain plates in compression and shear, of glass in bending, and of stressed plastics is markedly sensitive to exposure to the presence of chemical agents. These can be said to act in a catalytic manner and to decrease activation energies for fracture. The active reagents may be present in the atmosphere surrounding the specimen, in capillary liquids, in surface cracks or may migrate from surface layers (8). Similarly, the effect of surface-active agents on nucleation can be estimated quantitatively for processes governing such phase transitions as condensation, boiling, and cavitation. Thus fracture is not only a classical strengthof-materials or elasticity problem to be studied only from a mechanical viewpoint, but it is also a rate process in which common molecular and chemical effects enter strongly. In this area the training of the modern research chemical engineer should fit in well.

The concepts and ideas of reaction kinetics and of rate processes which are today an increasingly important province of activity for chemical engineers can enter into this old unit operation of crushing and also into the immensely important field of the strength of materials, with which our literature has been little concerned in the past. We have produced many new materials, many new synthetics, but have apparently not realized the chemical and rate aspects of their engineering strength properties. Modern development in solid-state physics also shows that new engineering approaches to solid materials are certainly needed.

In summary, this paper has attempted

to outline some of the newer areameasuring techniques, some advantageous methods of plotting, some industrial mill correlations, some laboratory results and finally has indicated directions for future research.

It is generally realized that the known economic mineral deposits of our country are being rapidly depleted in supplying our ever-expanding economy with the necessary materials of construction, maintenance, and war. Hence it behooves everyone to consider carefully the timing and direction of some of the research efforts that will be needed to meet these problems of the not too distant future. Important progress in the fields of crushing and fracture will not be rapid and will have to be based on other concepts than those prevailing at the present time.

# Acknowledgment

In this presentation the author has drawn for several of the figures upon the work of J. N. S. Kwong, J. T. Adams, J. F. Johnson, J. W. Axelson, L. J. Heney and N. F. Schulz, who have at various times worked as graduate students in the laboratories at the University of Minnesota.

#### Literature Cited

- Adams, J., Johnson, J., and Piret, E. L., Chem. Eng. Progress, 45, 655 (1950).
- Arnell, J. C., Can. J. Research, A27, 207 (1949).
- Axelson, J. W., and Piret, E. L., Ind. and Eng. Chem., 42, 665 (1950).
- Bond, F. C., Mining Engineering, 4, 484 (1952).
- Bond, F. C., and Wang, Jen-Tung, Trans. A.I.M.E., 187, 871 (1950).
- Fahrenwald, A. W., Hammer, O. W., Lee, H. E., and Staley, W. W., Trans. A.I.M.E., T.P. No. 416 (1931).
- Goudin, A. M., and Hukki, R. T., Mining Technology, 8, T.P. No. 1779 (1944).
- Gurney, G., and Pearson, S., Proc. Phys. Soc. (London), 62B, 469 (1949).
- Hatch, T., and Choate, S. P., J. Franklin Inst., 207, 369 (1929); 215, 27 (1933).
- Irwin, G. R., and Kies, J. A., Welding Journal Research Supplement (Feb., 1952).
- Johnson, J., Axelson, J., and Piret, E. L., Chem. Eng. Progress, 45, 708 (1950).
- Kwong, J., Adams, J., Johnson, J., and Piret, E. L., Chem. Eng. Progress, 45, 508 (1950).
- Machlin, E. S., and Nowick, A. S., Trans.
   A.I.M.E., 172, T.P. No. 2137 (1947).
- Martsell, F., and Svensson, J., Trans.
   A.I.M.E., 190, 981 (1951); Mining Engineering, 981 (November, 1951).
- Poncelet, E. F., Trans. A.I.M.E., T.P. No. 1684 (1944).
- Ratcliffe, A., Proc. Inst. Mech. Engrs., 162, 378 (1950).
- 17. Taylor, N. W., J. Applied Phys., 18, 943
- Symposium on Nucleation, Ind. and Eng. Chem., 44, 1269 (1952).

# TYPES OF GRINDING MILLS



# And When to Use Them

Henry W. Erickson

Allis-Chalmers Manufacturing Company, New York, New York

A great deal has been written concerning grinding and grinding mills in general, but most of the discussion has been highly technical and difficult to apply in actual practice. The many factors involved in grinding make it difficult to formulate specific rules governing general mill operation, and each case must be considered individually. Selection of a grinding mill for a given application is based on either test work or on experience with and operating data for a like or similar material. The great number and diversity of grinding problems in the chemical industry ensure that practically every type of grinding device has been used or tried. An effort will be made in this paper to cover as thoroughly as possible the many types of grinding mills in use today and to outline a guide for the economical and practical use of each.

Webster defines the verb "to grind" as "to reduce to fine particles." In the chemical industry this operation is concerned with such factors as the character of the material to be reduced, the feed size of the material, the fineness of the product required, and, to a great extent, the end use of the ground product.

It must be assumed that the material to be ground has been reduced to a proper size to be fed to the grinding mill. The size of feed to a mill is closely related to the fineness and character of product required. In coarse grinding operations, where fines are undesirable in the product, the feed is usually obtained from a crusher and ranges from about 34 to 1 in. in size, sometimes with removal of any finished material ahead of the mill. Generally speaking, the finer the product desired, the finer the feed to the mill should be. Both the coarseness of the feed and the degree of fines of the product are subject to practical limitations in common types of grinding mills, as determined by the grinding

mechanism employed. Preliminary crushing to proper mill feed size should always be carefully considered. Too coarse a feed, even though the grinding mill may take it, is uneconomical, and it should always be borne in mind that down to certain limits it is cheaper to crush in standard crushing devices than in a grinding mill.

The fineness of product and its end use are very closely related. In the majority of cases a material is ground only to a fineness necessary to fit the end use. Overgrinding would be a waste of energy with unnecessarily increased cost, added difficulties in classification or sizing, etc.

The physical and chemical characteristics of the material involved are of utmost importance. Among the many characteristics that govern the selection of proper equipment are hardness, crystalline structure, grindability, percentage of free moisture in feed, solubility, toxicity, melting or softening point, etc.

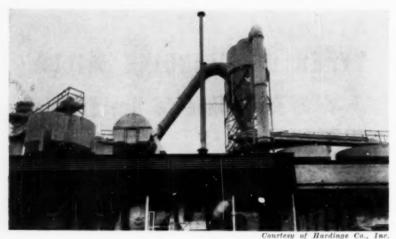
Noncontamination of product narrows the choice of a mill in a great many cases.

#### **Grinding Fundamentals**

Grinding problems are sometimes broken down and differentiated in terms of the relative fineness of the product, namely, coarse, intermediate, and fine grinding. It is almost impossible to set up a definite group for these three, but, roughly, coarse grinding can be classified as from 6 to 35 mesh; intermediate, from 35 to 70% passing 200 mesh; and fine grinding, from 70% minus 200 mesh down to 10 microns and even smaller.

In general, grinding operations may be defined under the following headings:

 Liberation or unlocking of valuable minerals or elements from waste material in order to obtain the valuable partian by subsequent concentration methods.



Conical ball mill grinding calcined phosphate rock.

 Grinding to a definite product size in order to meet requirements of various specific processes.

 Grinding to a definite product size set up for commercial requirements, such as for barite, feldspar, cement, obrasives and many other products that require no further treatment other than grinding to a definite size.

There are several terms used to designate the size or fineness of ground material. Mesh size describes the product in terms of limiting mesh sizes. In some operations the product is designated in terms of maximum mesh size. In some cases the product requirements are expressed as a size modulus, where it is desirable to control the product within certain mesh sizes; for example, it may be necessary to grind to all passing 65 mesh with a product containing not more than 25% passing 325 mesh. In various industries the product is defined in terms of specific surface area, which refers to the square centimeters of surface area per gram of ground material. This term is used particularly in the cement industry.

In a great many industries, where grinding is desired beyond the fineness designated above, size is measured in microns.

#### OPEN- AND CLOSED-CIRCUIT GRINDING

In open-circuit grinding, material is fed to the grinding mill at a rate to produce the finished product in one pass through the mill. The material to be ground must remain in the mill until every particle has been reduced to the specified size. Considerable energy is thereby wasted in regrinding the material already of finished size. Open circuits are used particularly where simplicity of layout may be the determining factor, or where the material to be ground does not lend itself to handling in classifying or sizing devices.

In closed-circuit grinding, the material is discharged from the mill into a separating device which separates and returns the oversize to the mill for further grinding with the new feed, and delivers the undersize as the finished

material of that circuit. No attempt is made to finish the reduction in a single pass through the mill, but, rather, every effort is made to remove the material from the system as soon as it reaches the required fineness, thus allowing the grinder to work on the oversize particles only. When grinding to a specified mesh size, an increase in capacity is obtained by closed-circuiting a mill. The most generally used separators for closed-circuit grinding are hydraulic classifiers, air classifiers, and screens.

#### STAGE GRINDING

In large plants where material must be ground to considerable fineness, it has been found that it is more efficient to grind in several stages of reduction, that is, to reduce the material step by step in different mills which are usually in closed circuit. Economic considerations, fineness of grind and initial cost of investment generally dictate the number of stages to be used. The advantage of simplicity and easier control in operation can be claimed for single-stage grinding. However, in large installations, multistage grinding is often justified by lower grinding costs.

#### WET- AND DRY-GRINDING

The choice between wet- or dry-grinding is dependent upon the use of the product or its subsequent processing. It is imperative to dry-grind many materials because of physical or chemical changes which occur if water or a solution is added. Wet-grinding with water (or with a concentrated solution of the soluble salts being ground) is generally preferred, because of the over-all economies of this operation.

Advantages of wet-grinding are

- 1. Lower power consumption per ton of product.
- Higher capacity per cubic foot of mill volume.
   Use of wet-screening or classification for close product control.
- 4. Elimination of the dust problem.
- Use of simple handling methods, such as pumps, pipes, and launderers.

Advantages of dry grinding are

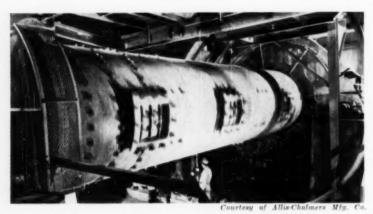
- Lower wear rate of mill liners and grinding media.
- Higher percentage of fines in mill product. In many cases this is desirable.

# **Grinding Mills and Their Scope**

Some of the types of mills most used in the chemical industry are revolving mills, rolls and roller mills, hammer mills, attrition and buhrstone mills, ringroll and ball-and-race mills, cage mills, colloid mills, fluid-energy mills, etc.

## REVOLVING MILLS

Probably the most used of all types of grinding mills is the revolving mill. Un-



Three-compartment ballpeb mill for finish-grinding cement clinker.

der this heading will be included various modifications of the fundamental principle of a cylinder or cone rotating on a horizontal axis and charged with some form of grinding medium. During the rotation of these mills the grinding media acquire rolling, cascading, and falling motions, and the impacts and grinding resulting from these motions are effective in comminuting the particles in the mass. Most revolving mills are lined with iron, steel, stone, or porcelain to protect the shell against wear, and this lining is so designed as to give the most effective action to the grinding media in the mill.

Except for revolving mills of special types, such as the batch or peripheral discharge mills, most mills under this classification are fed through a trunnion by means of a scoop, drum, combination, screw, or spout and discharged through an open trunnion, as in the overflow type of mill, or through a grate or diaphragm and thence through the trunnion.

The speed at which a mill is operated is of utmost importance, and the proper speed for a particular grind must be set for the most economical operation. Mill speeds are designated as revolutions per minute, and correct speeds are determined as percentages of critical speed, which may be defined as that speed at which the grinding media centrifuges against the mill liner. The critical speed may be calculated from the following formula:

Critical speed = 
$$\frac{76.63}{\sqrt{D}}$$

where

D = diameter inside of lining, ft.

Ball mills are usually operated at from 55 to 85% of critical speed, and rod mills at 50 to 55% with wet-grinding; tube mills with dry-grinding are commonly run at slightly lower speed than in wet-grinding. Generally, the smaller diameter mills operate at a higher percentage of critical speed than the larger mills.

Nomenclature of the various forms of revolving mills is not exact, but the following definitions and general classifications probably represent as closely as possible present practices.

Boll Mills. In all ball mills, iron or steel balls are used as the grinding media. The balls usually vary in diameter from 1½ to 5 in., and the ball charge used is from 45 to 50% of the internal volume, depending on the discharge head. The diameter of a cylindrical ball mill varies from 3 to 10½ ft., and the length varies from about one-half to twice the diameter. The nominal size of any cylindrical ball mill is indicated by the

diameter and length in the order given. Some manufacturers designate the size by diameter inside of shell, while others use the inside of liners. Nominal length is generally taken as the internal distance between end liners, otherwise known as the working length of the mill. With conical ball mills the sizes are given as the diameter and the length of the cylindrical section, in that order.

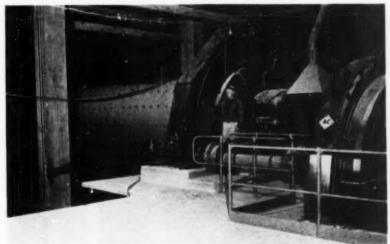
Generally speaking, ball mills are comparatively short as compared with their big brothers, the compartment and tube mills. Usually a ball mill is employed for intermediate grinding.

Tube Mills. Tube mills, the general term applied to mills of great length which are used for very fine grinding, are essentially the same as ball mills except for their greater length. They are divided into two general classifications, pebble mills and ballpeb or long ball mills.

grinding, all contained in one rotating element. It is built in single diameters of 3½ to 8 ft., two diameters of 7 to 10 ft. and 6 to 9 ft., and in lengths up to 50 ft.

Rod Mills. Rod mills are cylindrical mills employing steel rods as the grinding media. The length of these mills is generally about one and one-half to two times their diameter.

Peripheral-Screen-Type Ball Mills. In industry this mill is quite commonly known as the Krupp-type mill. Instead of the conventional liners, the mill lining consists of alloy-steel plates provided with perforations so that the material may discharge freely to screens arranged around the circumference of the mill. The limiting screens are usually protected by coarser screens to prevent unnecessary wear. The material that fails to pass the limiting screens is returned



Courtesy of Allis-Chalmers Mfg. Co

Two-compartment clinker-grinding mill in a cement plant.

Pebble mills employ flint or hard-rock pebbles as grinding media and stone linings. Where iron, steel, or any other metallic contamination from wear on media and liners cannot be tolerated, pebble mills are often used.

Ballpeb or long ball mills employ iron or steel balls as grinding media and iron or steel liners. The balls are smaller than those used in a ball mill, varying from 34- up to 1¼-in. diam. Longer ballpeb mills are usually divided into two compartments to vary the ball size.

Comportment Mills. A compartment mill is a combination of a ball mill and a tube mill of the ballpeb type in that it will handle as coarse a feed as will the ball mill and grind as fine as the tube mill. It is actually several mills in stage

continuously to the grinding chamber as the mill revolves. This mill therefore provides close-circuiting with screens within a single unit. It is also arranged with a totally enclosed, dustproof housing so that the unit is suitable for those applications where dusting must be controlled. The mill is mounted on two solid bearings and is fed by a chute on one end.

Botch Milb. As defined by its name, this type of revolving mill is used for intermittent or batch operation. The mill consists essentially of a revolving element charged with a fixed number of grinding balls or pebbles and lined with iron, steel, or stone. The mill is charged with the amount of material to be ground, usually rotated for a definite

period of time or number of revolutions, and then shut down for discharging. The opening for feeding and discharging has a removable screen, which acts to retain the grinding media and unload the ground material on discharging. The mill may be operated wet or dry, depending on the grinding job for which it is being used.

## APPLICATION OF REVOLVING MILLS

Boll Mills. Ball mills are generally applied to wet-grinding to give a product of from 14 to 200 mesh and occasionally as low as 325 mesh. However, for fine grinding it is necessary to arrange the mill in closed circuit with a classifying device, in order to obtain a proper capacity with the fineness desired. Ball mills are also used for dry-grinding, but where possible wet-grinding is generally more efficient.

The largest application for ball mills is in the wet-grinding of metallic ores,

similar to that of pebble mills, but the mills are of heavier construction to withstand heavy steel-ball loads in place of pebbles. They are used for fine grinding to give a product of from 100 to as low as 325 mesh and are generally used for dry-grinding in closed circuit with an air separator.

To differentiate between a ball mill and a ballpeb mill, the ball mill is generally used for wet-grinding to intermediate or fairly fine sizes, whereas the ballpeb mill is used for dry-grinding or for grinding to a very fine product. The greater length of the ballpeb mill and the smaller balls used are the principal factors in making the ballpeb mill suitable for dry-grinding to an extreme fineness.

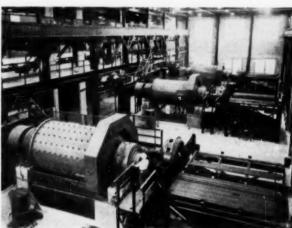
For many years pebble mills were used quite generally for fine grinding. Owing to the scarcity and high cost of goodquality grinding pebbles, however, together with certain inherent advantages the grinding of cement and fine grinding of abrasives, ferro alloys, etc.

Rod Mills. Rod mills are generally applied to coarse grinding from a nominal feed of ¾ in. to give a product of from 10 to 35 mesh and are occasionally used for grinding to as low as 65 mesh in limited cases. Rod mills are used for either wet- or dry-grinding depending on the process involved.

Rods have less tendency to overgrind a portion of the feed than balls, with the result that rod mills are used in place of ball mills when a coarse product is desired and fines must be held to a minimum.

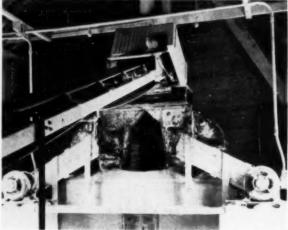
The rod mill can be used effectively as a primary mill in preparing ball-mill feed, thus replacing fine crushers or rolls. Rod mills are essentially well adapted to production of granular prodnets.

Peripheral-Screen-Type Ball Mills. This mill



Courtesy of Allis-Chalmers Mfg. Co.

Three rod mills in iron concentrator. Note rod charger at discharge end of each mill.



Courtesy of Allis-Chalmers Mfg. Co.
Hammer mills with split feed arrangement operating on agricultural limestone.

although there are a multitude of other applications, such as grinding of slags, nonmetallics, abrasives, etc.

In special cases, where standard ball or liner wear will contaminate the product, ball mills have been equipped with stainless-steel liners and charged with special stainless-steel grinding media.

Pebble Mills. Pebble mills are used for grinding from 50 to 200 mesh, with a low of 325 mesh where it is necessary to obtain a product containing a minimum of metallic contamination. This is particularly true in the ceramic industry. Pebble mills are used in open or closed circuit and are adapted to either wetor dry-grinding.

Ballpeb Mills. Ballpeb-mill design is

and higher capacity of the ballpeb mill, wherever possible this type of mill has replaced the pebble mill.

Comportment Mills. As explained before, the compartment mill is a combination of coarse and fine grinding units in one revolving element. With this mill, any grindable material of 11/2-in. size or less can be efficiently reduced to a finished product in one operation either in wetor dry-grinding. The size of grinding media in each compartment is reduced to give the most effective work on the product of each preceding compartment. The application of the compartment mill is very similar to the ballpeb or long ball mill except that the compartment mill will handle a much coarser feed. It has found extensive use, particularly in

has fairly limited use, being generally small and of low capacity. As the speed is low, balls do not cascade, and grinding is mainly by attrition.

Botch Mills. The batch mill has its greatest application where relatively small capacities are required and many different products are being made at one time, as in the pigment industry. Here, at plants grinding a variety of colors, batteries of batch mills are in use, each mill being used exclusively for one specific color. In an operation of this kind, in most cases capacities are not large enough to warrant a continuous mill, and such a mill would be practically impossible to clean between runs of one color and another without contamination.

In cases where small quantities are to be ground for a predetermined time, batch mills are used. Also, generally speaking, batch mills are used for determining grindabilities of various materials in laboratory testing.

#### ROLLS AND ROLLER MILLS

Rolls. Rolls are generally considered as fine crushers rather than as grinders but, as they are still being used in several operations as coarse grinders, they should be mentioned. Rolls consist of two iron or steel cylinders of equal diameter revolving toward each other at the same speed. Rolls crush by direct pressure and are usually set to a particular size. They are sometimes used to reduce material to 10 or 12 mesh and in rare cases to 20 mesh.

They are limited in capacity, and size of feed is governed by the angle of nip between the rolls. They are sometimes used on not too hard, friable material where abrasion on the rolls is not too great. Being expensive to maintain, they have been replaced by rod mills or other more economical types of machines, even for coarser reduction than the 10 or 12 mesh mentioned.

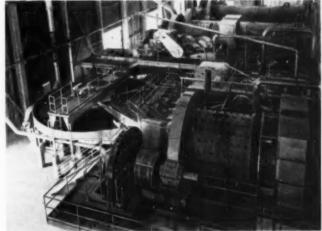
Roller Mills. The name roller mills is applied to several types of mills that in general are operated to reduce by direct pressure and shearing between rolls or rolling action of a heavy circular roll against a vertical, inclined, or horizontal surface. Generally speaking, they are used for dry-grinding of relatively soft materials.

Roller mills, such as used as standard equipment in the grinding of food products, have found extensive use for the production of granular Fuller's earth, salt, kaolin, etc. They are essentially the same as crushing rolls, except that the rolls are serrated or grooved and are operated at different speeds, reduction being accomplished by combined pressure and shearing action. They are used for special applications where the material is not too abrasive, and where small capacities are required.

Ring-roll roller mills, with heavy horizontal shaft rollers grinding by gravity pressure on a circular die, or roller mills that grind by the centrifugal force of steel rollers revolving against the inner surface of a vertical or inclined steel ring or die, are of many makes and variations.

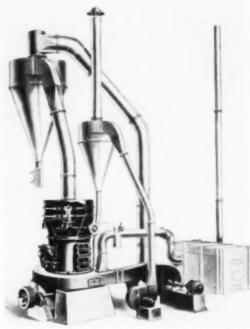
## IMPACT PULVERIZERS

Hommer Mills. Hanniner mills or swing hammer pulverizers are of many makes and designs but consist essentially of multiple arms with breaker heads mounted on a horizontal high-speed shaft within a casing which is equipped



Courtesy of Darr Ca

Two-stage, closed-circuit grinding arrangement in a cement plant.



Courtes) of Engineend Pulverizer Division.

Roller mill equipped for drying while grinding.

with a feed opening at the top and some form of grate or screen near the bottom for discharging the finished product. The casing or body of the machine is lined with wear-resisting plates and usually fitted with specially designed breaker plates, varying according to the make of the machine, to take the impact of the pieces struck by the hammers and to change the direction of the particles in the mill.

Pulverizing in this type of mill is accomplished by impact of the hammers on the feed material, impact of material against the breaker plates, and impact of particles of the material on each other. Material is retained in the mill until it is of finished size, ready to pass through the openings in the grates or screens.

The hammer mill is used extensively for pulverizing limestone and non-abrasive materials, where only top sizing is required and where fines are not objectionable. The inherent design of this machine enables it to take a fairly large feed and give a high ratio of reduction, but its use on abrasive materials (above 5% silica or equivalent) is

usually prohibitive because of excessive cost of maintenance.

There are also several makes of hammer mills of the vertical type, the principle being the same except that the hammers are mounted on a high-speed vertical shaft.

Fluid-energy Milh. The fluid-energy mill is comparatively new in the field of comminution. It is being considered here under Impact Pulverizers since reduction of particles in the mill is accomplished by impact of particles on each other. To understand the operation of this mill a description of one make of mill of this type is given herein. Several of the mills described are being operated by a northern New York tale company grinding tale down to micron sizes.

The mills are about 8 ft. high and resemble oversize chain links or elongated doughnuts. Each mill is made up of three sections of cast alloy steel, which, when put together, form a hollow casing of variable cross section similar to that of a wind tunnel. A reduction chamber in the lower section of the mill has several nozzles placed at an angle to the path of the air in the mill. Hot air at high pressure comes out of these jets at a speed of about 1600 ft./sec. Inside the mill this air whirls around at velocities of 200 to 600 ft./sec. A crushed and fairly finely ground material enters the mill through a Venturi-injection system near the bottom. The material is picked up by the air from the jets and set in violent motion. The particles collide with each other and with those already circulating through the mill at terrific speed and break one another to bits. Most of the actual breakage occurs in the reduction chamber. There are never more than a few pounds of material in the mill at one time, but the velocity is so great that several tons will pass a given point in one minute. The method of withdrawal of finished material is ingenious. As the mill is operated, air is continuously being withdrawn through an opening in the inside wall of the top section. Particles passing this opening are subjected to two forces: inertia, which helps to keep them on their course, and the drag of the air leaving the mill, The latter is adjusted to the desired rate for a desired size, and when a particle reaches this size, the air drag overcomes the inertia of the particle and it leaves the mill.

The operation of this mill has been described at some length, since it is believed that it may have considerable use in extremely fine grinding. Data are not available on actual operating and maintenance costs.

#### ATTRITION AND BUHRSTONE MILLS

The term attrition mill generally re-

fers to a horizontal or vertical doubledisk type of grinder. Material to be ground is fed between two plates with a preset opening, the plate surfaces so formed as to allow the material to be fed between them, the plate faces designed to give the maximum shearing and attrition action on the material, and the plates operated at high speeds in opposite directions. One plate is generally fixed and the other adjustable. The surfaces of the plates are made of abrasion-resisting alloy. The origin of the attrition mill is probably the old stone mill used for grinding grain. The buhrstone mill, which is still being used successfully on specific grinding problems, consists of two circular stones revolving in opposite directions. In design and operation, it is similar to the attrition mill.

#### SPECIAL GRINDING PROBLEMS

There are some special grinding problems to which no standard type of mill can be applied and where modifications and changes are necessary; for example:

- If material being ground is toxic, means must be taken to prevent any of the product from getting out into the working areas.
- Certain materials such as resins have a low melting and softening point. Since in all grinding operations heat is generated, modification must be made to keep the temperature down in the mill, and only certain types

- of mills are adaptable to such modifications.
- 3. Some materials such as aluminum, sutfur, etc., have a high affinity for oxygen, and, when ground fine, thus exposing more area, these materials cause explosion hazards when processed in an atmosphere of air. In such cases it is necessary to provide means to grind in an atmosphere of inert gas, such as carbon dioxide.

#### Conclusions

For any particular grinding problem, careful study should be made of all phases of the problem in order that a grinding mill may give the most practical and economical results.

Generally speaking, the energy consumed or the horsepower required to reduce from a certain size of feed of the same material to a product of the set specifications will be the same regardless of the type of mill used.

Owing to inherent principles involved in each type of mill, each has certain limitations, within which it is practical and economical to operate it.

Since the economics of a grinding mill is usually based on cost per pound or per ton of finished product, cost of maintenance of the mill is of prime importance. Maintenance costs consist mainly in cost of replacement of grinding surfaces and time lost in making such replacements.

On abrasive materials, slow-speed mills are more practical and economical than high-speed mills.

# UNUSUAL TECHNIQUES IN GRINDING



J. Howard Foote

Pulverizing Machinery Company, Summit, New Jersey

Many who are daily confronted with grinding problems handle them casually. To remedy this attitude, most of the companies actively engaged in the manufacture of grinding equipment are ready to render engineering advice and guidance toward the best and most economical solution of most problems encountered in industry.

Manufacturers of grinding equipment visit many plants embodying all types of processing in an attempt to adapt grinding equipment to specific problems. These efforts and studies have resulted in techniques, many of which have been used on repeated occasions toward overcoming similar problems while others have been one-shot methods that were able to overcome a very specialized existing problem but did not lend themselves in exactly the same form to other problems.

The science of grinding embraces all particle sizing from granulations, generally ground 10-80 mesh, to ultrafine powders ( $44\mu$  and smaller). There are many techniques that may be used in conjunction with grinding to improve the general operation. A few of the major ones follow:

- Grinding atmosphere—temperature, moisture, composition.
- 2. Grinding in the form of slurries or sludges.
- Treatment of the material prior to grinding and the admixing of various inert grinding aids to produce a more grindable product.
- Treatment of the material subsequent to grinding.
- Use of inert atmospheres and addition of special atmospheres to produce a chemical reaction during particle-size reduction.
- Use of several types of grinding equipment in tandem to produce varying characteristics.

These techniques are additional to adjustments or refinements of the grinding machine. In impact pulverizing there are many modifications in the basic machine that will permit the efficient comminution of materials to be finely ground, as are pigments; to be granulated, as are plastic molding powders, pharmaceutical products, etc.; or to be ground to special tolerances. Many installations of grinding machinery are used where only blending is necessary, as all the ingredients are fed in satisfactory fineness.

Similar modifications are available for other types of grinding equipment. Manufacturers and users of ball mills, rod mills, etc., have found that variables dealing with speed, quantity of balls or rods, weights and sizes of balls and rods, loading of the mill itself-all have definite bearing on the product and particle size ultimately produced by this equipment. The grinding equipment available in the fluid-energy field also has modifications and techniques that are combined by the manufacturer in such a way as to make the equipment most suitable for the problem at hand. As is natural in a competitive era, many problem solutions are being closely guarded. The dissemination of knowledge therefore has been retarded, and the solutions fall into what is called "know how." Since "know how" is very often guarded as an asset, these solutions are seldom made available for publication. As far as the manufacturer is concerned, however, it is his responsibility to try to remain always ahead, or at least abreast, of current problems and to provide or develop techniques for their solution. Development of the techniques mentioned above follows.

## **Grinding Atmosphere**

With the development of the plastics field have come requirements for the grinding or size reduction of various plastic products that have low melting points and are extremely tough. Because of the toughness of the material it is not at all unusual to find that fairly large amounts of power are required to effect the size reduction specified. The heat generated by this power often exceeds the softening points of these plastics.

and a softening action takes place in the grinding zone. Such melting necessitates a temporary shut-down. The development of many new and powerful insecticides also has produced a group of products that are heat-sensitive and need fine grinding.

An answer to these problems seems to have been worked out by chilling the material prior to grinding, either through storage, if practical, in a childed atmosphere or through the mixing of crushed dry ice with the material before grinding. When this method is used, it is often found advantageous to pipe chilled air into the grinding chamber so that the entire grinding process may be accomplished in a reduced-temperature atmosphere. Stearic acid, for example, is being ground to a 100-mesh powder successfully with dry ice and conditioned air.

Recently there have been articles in the literature relative to the use of liquid nitrogen as a refrigerant. Because of the extremely low temperatures developed with liquid nitrogen, it is often possible through a specially designed heat exchanger to grind without resorting to the initial chilling of the feed material. Here it would be well to insert a caution if refrigerants with a temperature in the range of liquid nitrogen are used. Machinery fabricated of cast iron or steel should not be subjected to these very low temperatures, which cause it to become brittle. All machinery should be of stainless steel or other cold-resisting

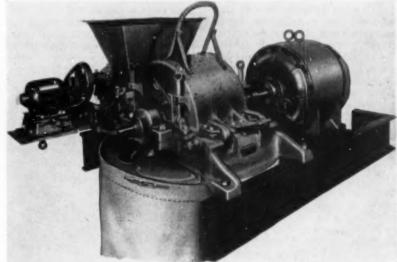
The advantage of heating certain types of materials prior to grinding is also very noticeable. Mention may be made of materials such as carbon-paper ink, asphalt mixtures, certain food products, and other wax and paraffin products which, because of their low melting point, are more easily handled in liquid form rather than as solids. Generally these materials are mixtures of suspended solids in low-melting-point vehicles where grinding is necessary for either particle-size reduction, dispersion of solids, or both. In such cases it is necessary to preheat the materials prior to grinding and then to control the heat during grinding by steam or hot-water jacketing of the mill. In addition, it is best to heat the air fed to the grinding equipment if air is circulating, so that there is no tendency of the warm material to congeal on surfaces not easily reached by jackets.

# **Grinding Slurries or Sludges**

Those products which by nature are either sludges or slurries and on which grinding is required are easily handled in the sludge or slurry form. As a matter of fact, very often on difficult materials finer adjustments of the grinding equipment can be made when the material is handled in these forms. Whether a material will be ground as a slurry or sludge is a matter of economics. It might be borne in mind that where a dry product is received in a fairly coarse form and subsequent processing requires a slurry or a sludge, it is often practical to prepare this slurry or sludge in grinding equipment thereby obtaining the effect of both the grinding and the slurrying step simultaneously.

# Treatment Prior to Grinding

This category presents a field which



Coartens at Paterrizing Machinery Co.

An impact mill for granular or fine grinds. Maximum capacity 25,000 lb./hr. Particle-size range from 10 mesh to 99.9% through 325 mesh.

could well absorb the entire contents of a paper since there are many treatments available for use prior to grinding. First, the matter of crushing or presizing of a feed material is extremely important if the raw material to be handled is large lumps. The crushing stage should be, as far as possible, engineered in keeping with subsequent grinding operation. As an example, when crushing or presizing plastic molding compound the crushing should reduce only to the proper feed size without fines (by fines are meant particles smaller than about 80 mesh). Since the finished product should have a minimum of these 80-mesh particles, too much crushing may develop excessive fines to which those generated in grinding will be added. Where a final ground product of greatest fineness is wanted, the crushing need not be so precise. It would be well to admit that crushing, as differing from grinding, is a separate problem requiring considerable study.

Another pretreatment very often worth considering is screening or air separation of the feed material, as it may contain a large percentage of product already of satisfactory fineness. There are those chemicals which have very difficult grinding characteristics but which, in their unground state, contain 30 to 50%, or more, acceptably fine material. When this condition is observed, study should be conducted to compare capital expense for grinding equipment only, with the cost of smaller grinding equipment and preceding screening or separation equipment.

Another pretreatment technique is the use of an inert grinding aid. This technique has been most widely used in the insecticide field, while grinding DDT, benzenehexichloride, etc. These materials lend themselves to this procedure as they must be diluted before use. Therefore, the inert first helps the grinding and second acts as the carrier.

The grinding of fibrous materials, for instance derris root, into fine-particle size has always been a problem. It now has been found that passing these fibrous materials through high-pressure compression rolls renders the fibers brittle and much more grindable.

# Treatment Subsequent to Grinding

There are several possible subsequent treatments that assist in producing the desired product more economically. The use of screening following grinding is important when products containing very closely sized particles are required. A plastic molding compound, for instance, has to be sized so as to bracket the bulk of material between 14 and 80 mesh. Particles larger than 14 mesh can be recycled from the separation

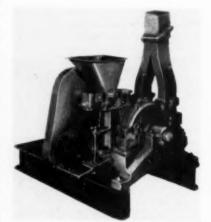
stage for further grinding, but particles finer than 80 mesh are a disadvantage. As a caution, this recycling process is uneconomical if the circulating load of oversize exceeds 20 or 30% of the feed to the separation step. Screening or air-separation equipment is indicated on those resistant materials which cannot be ground to desired fineness in one step. When this problem is encountered, it will be found more economical to grind with a coarser set-up, possibly decreasing the ground product in fineness so that it runs in the neighborhood of 80 to 85% through the desired mesh size, then to feed this product to the classifying equipment, screens, air separators, etc., to recover all the desirable product within the bounds of the efficiency of the classifiers, and then to return the oversize to the grinding unit. Very often the use of this type of system will show a resulting increase in the over-all capacity. For example, grinding machinery that will produce 1000 lb./hr. of a product analyzing 98.5% through 200 mesh will produce possibly 2000 lb./hr, or more of a product analyzing 90% through 200 mesh at about the same horsepower. This capacity increase will, after suitable separation, provide 1800 lb./hr. of a desired product against only 985 lb./hr. without separation. Pigments. pharmaceuticals, etc., which require reduction to micron size, can be handled in grinding machines that have integral air-separation, conveying, and collecting elements. Impact equipment, fluid-energy equipment, and air-swept ball, tube, and rod mills fall into this category. Generally, these have as one of their basic characteristics a design that will permit the oversize material from the separation stage to be returned or retained automatically for further grinding and subsequent presentation to the classifying steps. Methods so far discussed deal mainly with treatments subsequent to grinding that will help produce the desired product generally more economically. Other treatments are also possible and are coming to the fore with the trend toward automatic handling of materials. The use of low-pressure air-conveying systems following a grinding stage is becoming increasingly important, as it has proven satisfactory in treating and moving the ground material from the sizereduction machine to some other area. With this method it is entirely possible to condition the material during its handling period by surrounding it with conditioned air or gases. Quite often a product will show a high temperature rise during grinding. As the product may be damaged by long exposure to heat, some form of heat dissipation is advisable. Air conveying fills this need. If room-temperature air is not suitable,

then the air may be chilled or further conditioned as required. It is generally safe to assume that most ground materials can be conveyed in ducts at velocities of 5000 ft./min. using 25 cu.ft. of fluid/lb. of material, but special consideration of each problem often permits using fluid ratios as low as 10 cu.ft./lb. of material.

Another treatment that has proved effective is collecting the ground dry product in a type of agitator tank filled with liquid vehicle, such as water, oil, etc., and into which the solids are incorporated as they are discharged from the grinding stage. This method is used successfully in the production of carbonblack slurries for the synthetic-rubber program. In passing, it is interesting to note the development of this process, as originally it was intended that the slurrying take place during the grinding operation. However, this was uneconomical. as higher capacities could be obtained by dry-grinding the carbon black and slurrying it as a subsequent treatment.

# **Inert and Special Atmospheres**

Many materials are pyrophoric, easily oxidized, or characterized by other unusual properties. These characteristics can be controlled by the introduction of



Courtesy of Pulverizing Machinery Co.

Pulverizer with built-in air classification, for grinding in the lower micron range. Maximum capacity 1200 lb./hr. Particle-size range from 99.3% through 325 mesh down to an average of  $2\mu$ .

proper inert atmospheres during the grinding stage and the retention of these solids in the atmosphere during the subsequent processing period. However, the use of this type of system has to be carefully evaluated from the economic aspect. Justification will often depend on ability to recycle the inert atmosphere unless there is an ample and readily accessible source of gas. Washed

flue gas has proved valuable and economical as an inert atmosphere. If a closed or recycling system is used, consideration must be given to the possible buildup of temperatures due to the input of mechanical heat. If the temperature must be maintained at a definite level, heat exchangers are required. Current operations in industry prove the feasibility of using special atmospheres induced through the grinding equipment to effect chemical reaction. The atmosphere in this case serves two purposes: (1) the cleaning of the grinding chamber of acceptable fineness powders, and (2) production of the desired chemical reaction in these powders.

# **Grinding Equipment in Tandem**

There are chemicals which when ground have to be measured in terms other than particle size. Often in order to obtain characteristics such as oil absorption, special dispersions, etc., two different types of grinding equipment must be used. Unfortunately there are no rules or points of guidance that may be described in the solutions of these problems. When these problems are encountered, an experimental program and the aid of various manufacturers must be enlisted. Among interesting and unusual applications of ball mills are the following:

Production of a lead axide suitable for battery electrodes in a continuous mill requires standard continuous ball mills. The mills are generally equipped with a water spray on the autside of the shell which is controlled by a thermostat inserted into the discharge end of the mill. The discharge end is provided with a dustless discharge housing, to which a controllable air draft is connected. The mill charge does not contain

any steel balls or pebbles, but only cast lead balls or slugs. The grinding operation would normally produce flake particles of lead. As the mill is operated, however, its temperature increases. When the mill temperature has risen to approximately 250° F., the lead begins to oxidize rapidly. The purpose of the air draft is to supply sufficient oxygen to maintain the rate of oxidation of the lead. As the lead oxidizes, heat is generated in addition to the heat of grinding. The air flow through the mill removes some of this heat, but on larger mills it is necessary to control the temperature by water applied to the outside of the mill. The mill operates, generally, at a temperature between 300 and 400° F., and at this temperature the product obtained has approximately 80% lead oxide, the balance being metallic lead. The lead produced is not satisfactory for chemical litharge but is satisfactory oxide for storage batteries. There are many occasions when a chemical reaction is performed in a ball mill. Many times chemical leaching is accomplished by grinding in an acid solution. In the mining industry, gold can be separated from its ore by leaching with a potassium cyanide solution. When this operation is used, the ore is pulverized in the mill with a solution of potassium cyanide.

In a particular application it is proposed to cause a reaction between a liquid and a solid inside a continuous ball mill. This reaction is such that the liquid, upon completion of the reaction, is vaporized and can be removed as a vapor to a condenser, where it is separated in a liquid form. The solid materials are little changed in the reaction and are retained in the mill for a much longer period of time. In this particular reaction, it is necessary to operate the mill with considerable pressure internally and also to provide heating of the mill contents. The reaction that occurs in the mill has a tendency to form a paste which collects on the walls of the mill and also forms hard agglomerates. A ball mill breaks down the agglomerates as

rapidly as they are formed and also keeps the paste from collecting on the walls, so that a high heat transfer may be maintained.

Several interesting techniques in the use of fluid-energy mills are outlined below:

Coating of materials with a film of approximately Langmuir thickness is obtained by premixing with the feed as little as 0.25% of a coating agent that is volatilized by heated fluid. Grinding and coating occur simultaneously, each particle being coated.

Materials that have a cellular structure capable of absorbing maisture are ground by maistening such materials before milling. Heated fluid is then used to rupture the bundles. Splitting usually occurs along the axis of the fiber.

Fluid-energy grinding of certain pharmaceuticals which require sterile conditions throughout is achieved by sterilizing the compressed air used. Fluid-energy mills are particularly useful in connection with some materials which tend to adhere to the mill. This is especially the case when a material is heat-sensitive. As compressed air expands from the orifices, the cooling effect from expansion of the fluid offsets the heat generated by the grinding process. The air remains at room temperatures, or lower, throughout the process.

# Impact Pulverizer Mill

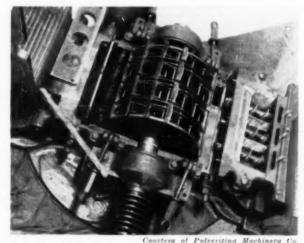
So far this paper has dealt almost entirely with techniques for improving the grinding operation. The grinding operation itself will now be considered, with emphasis on impact pulverizer problems.

The impact-type pulverizer, sometimes called the hammer mill, is a machine which has a high-speed rotor and which does not have any metal-to-metal contact within its casing. The grinding is accomplished by fast moving hammers impacting against slower moving particles. Roughly, the grinding energy can be expressed as being equal to the difference in velocity between the particle and the hammer.

Probably the easiest materials to grind are clusters of small particles agglomerated into a large lump. Here it is necessary to break the cementing action between parent particles which holds them together in the cluster. This is particularly true of the dry-color field, where generally relatively high capacities may be obtained with fairly low power inputs. However, it should be pointed out that during the grinding all agglomerates are not completely disintee grated and the particles returned to their original sizes. Also, all dry colors do not fall into this soft category.

Probably the next best grinding material is the crystalline type, such as sugar. These crystals contain cleavage lines which make them very susceptible to size reduction through impact.

The third and toughest grinding problem is that of the reduction of fibrous



Typical open view of the grinding chamber of a pulverizer, showing hammer assemblage, feed screws, and part of multiple deflector cover liner.



Bantam impact mill for pilot-plant or small-batch production. Maximum capacity 200 lb./hr.

materials (wood flour, cellulose products, roots, etc.) into a product that has some semblance of a free-flowing powder. It might be well to note that it is almost a physical impossibility to develop free-flowing fibrous powders in impact pulverizers. If such a product is required, it is necessary to use ball mills, tube mills, or similar equipment.

The impact pulverizer through hammer design, rotor speed, type of screens used, type of casing, etc., can easily be adjusted to produce particles from a coarse granulation with minimum fines up to an ultrafine powder in the micron range.

#### HAMMER DESIGN

When granulation or closely controlled particle size grinds are required, it is often necessary to resort to a bar-type hammer rotor. As the name implies, these hammers are manufactured from various sizes of bar stock. When they are installed, the width is placed parallel to rotation. Hammers with impact faces 1/16, 1/8, 1/4, and 3/4 in. wide are common. The specific type is selected by the analysis of the problem. A fairly safe general rule reveals a gradual increase in product fineness as the hammer-face thickness is increased. For granulations of very soft materials, it is not unusual to resort to bar-type hammers which have been sharpened on the leading edge to convert their action from true impact to a cutting-type action. Where fine grinding is necessary, it is generally most practical to resort to a hammer having a single-piece head supported by one, two, or more legs from the rotor disks themselves.

#### ROTOR SPEEDS

Speed is very important to grinding, regardless of what principle of grinding is used. As far as impact grinding is concerned, the true measure of speed is not expressed in revolutions per minute but rather in terms of peripheral speed of the hammer tips. It should never be overlooked that it is the tip speed of the hammer which does the work. Rotor speeds may vary all the way from 2500 up to 22,000 ft./min. or more. Peripheral speeds in excess of 25,000 ft./min. may be questionable economically, as the windage losses at these very high speeds become excessive, and ultimately large power inputs are required to overcome the idle load.

On the other end of the speed scale, the use of low speeds in the solution of grinding problems must be carefully observed, as it is possible to drop the rotor speed below the critical impact speed. The critical impact speed is observed when the speed of the rotor is so reduced and no longer has the ability to grind the material by impact and therefore reverts to a mulling action where the material is worn by itself and the grinding elements to a finer size. Operation below the critical impact speed results in rapid temperature rise and overloading of the pulverizer. Generally the ground particles will appear to have smooth rounded surfaces instead of sharp irregular surfaces developed by true impact.

#### SCREENS

There are a wide variety of methods used to retain materials in the grinding chamber of impact pulverizers, and by common usage these methods have all come to be known as screens. Most screens that are used are not woven but rather are perforated metal plates with holes and slots of varying dimensions and patterns. There are other ramifications of retaining equipment, one of the most widely used probably being grid bars, which are heavy and rugged in construction and lend themselves very well to use on grinding machines in the handling of abrasive material or obtaining of coarse grinds.

In any discussion of size and patterns of available retaining screens, it is well to remember that the particle size of the material passing through any given screen will be much finer than the actual opening of the screen. This is due to the particle having to exit through the perforations of the screen on a path approximately tangential to the rotor, which makes the effective screen perforation much smaller than the actual opening. It therefore is possible to obtain a fine particle size with a relatively coarse retaining screen.

There are three basic types of screens in popular use today. First is the roundhole screen. This is the strongest but the most difficult to keep free from clogging during fine grinding operation,

Next is the herringbone pattern of slotted screen openings which may be relied upon to remain operative for continuous use. However, it should be pointed out that a herringbone screen with the width of the slot opening equal to the diameter of a round perforated screen will grind somewhat coarser, the degree of coarseness being dependent on the type of material ground. But materials of a fibrous nature should not be ground on herringbone screens, as it is possible for the fibers to align themselves with the slots and pass through, thereby permitting a long fiber to get into the finely ground materials.

The third popular type of screen is called the cross slot. As the name implies, these slots are patterned at right angles to the path of travel of the hammers. These screens are not often used in the fine size on dry-grinding because the small slots clog too readily. They are particularly effective in handling

slurries and sludges.

In the handling of certain materials, screens may be worn by particles passing over their surfaces as they exit. Therefore, the surfaces of these screens should be carefully inspected periodically to detect surface wear. The point of greatest wear on a screen is usually the far edge of the slot or hole in the direction of rotation. The wear is evidenced by a bevelling of the far edge of the screen hole. Thus the product which should normally exit is deflected and retained in the grinding chamber, thereby causing a decrease in capacity and a moderate increase in fineness. Peak efficiency demands periodic inspection of the screen on a schedule indicated by the nature of the material being ground. When the screen is replaced after inspection, it should be turned 180°, so that the hammers pass over the screen holes in the opposite direction, With this technique the usable life of the screens will be increased, and in all probability the over-all capacity of the grinding equipment during the life of the screen will be more satisfactory.

There are many other features in the form of refinements and modifications which could be discussed, but it is far more interesting and probably more beneficial to discuss these in relation to certain problems rather than try to treat them as generalities. Also it should be recognized that the information in this paper is a long way from covering all the ramifications on all types of available grinding equipment. An attempt has been made to condense a large subject into a resumé and to discuss only those items that could have a wide bearing on many problems.

#### Acknowledgment

The author is grateful to R. E. King, chief division engineer, The Patterson Foundry & Machine Company, and C. H. Kidwell, president, Reduction Engineering Corporation, for their contributions.

# METERING LIQUID SULFUR

E. S. BOE\*, C. E. BUTTERWORTH†, and J. R. WEST‡

Texas Gulf Sulphur Company, Newgulf, Texas

METERING liquid sulfur has received considerable attention in recent years in industries which manufacture sulfur dioxide, sulfuric acid, carbon bisulfide, hydrogen sulfide, thiophene and other chemicals from elemental sulfur. Actually, handling and metering clean (free of contaminants) sulfur as a liquid does not require equipment different in design from that needed for other liquids if consideration is given to the necessity of keeping temperatures above 125°C, and below 150°C. Trouble arises where liquid brimstone is contaminated with suspended matter and/or sulfuric acid.

Gulf-coast brimstone as it comes from the wells contains no moisture or acidity, less than 0.01% of ash and a trace of sulfur soluble organic matter and may be readily handled and metered. The user's difficulties start in his stockpile and in shipment.

Ordinarily sulfur is shipped in boxcars, gondola cars, open cars and barges. Contaminants added during transit appear as suspended matter in the melted solid and cause clogging of metering equipment that operates with parts moving or placed at close distances to one another or fouling of orifices. Foreign substances may also accumulate in the solid where it is stockpiled by the user in the open for long periods.

Furthermore, users' stockpiles of broken brimstone in the open usually develop small quantities of weak sulfuric acid due to the moisture from rain, fog, dew, or mist, and to air (2). This oxidation may also be brought about by Liquid sulfur has been metered in quantity meters, head meters, a rotameter and in weirs. An oscillating piston type measured the flow to within 2% of that given by a calibrated tank when the flow was 1 to 7 gal./min. For metering with a proportioning pump, the worst error was 3.7% in the range of 0.2 to 1.42 long ton/hr. It was learned that coefficients of discharge for an orifice meter can be applied to liquid sulfur with an average error of less than 3%. However, for a Venturi meter, the observed coefficients deviated as much as 18.5% from those reported in the literature, with an average of 9.9%. In the range of 1.0 to 2.0 long tons/hr., a rotameter checked the calibrated tank within an average of 2.5%. A 30° V-notch weir agreed within an average of 0.4%, but a 60° and a 90° deviated by average percentages of 6.9 and 7.6, respectively. For a rectangular weir the observed flow came within an average of 1.7% of the calibrated tank.

TABLE 1	TYPES OF	METERS	TRIED WIT	H LIGHTD	STILETIE

T.	BLE 1. TYPES OF ME	TERS TRIED WITH L	IQUID SULFUR
Quantity Meters	Head Meters	Area Meter	Weirs
Oscillating	Orifice	Rotameter	V notch
firstou	Venturi		Rectangular
Measuring tank			
Proportioning piston pump			

sulfur bacteria. Wet, finely divided sulfur, out of contact with air, reacts with iron and steel to form iron sulfide (15).

Most of the trouble develops after the solid from the user's stockpile is sent to the melter. The moisture causes foaming in the melter which must be designed with this factor in mind. As time passes, the sulfuric acid concentrates in the melter and often cokes the organic matter in the brimstone to form black specks in the liquid. With very acid sulfur the black specks may agglomerate to form a floating asphaltic scum which, having an acid reaction, is corrosive to iron and steel.

If one then attempts to meter brimstone containing suspended inorganic particles, an asphaltic scum, and perhaps products of corrosion, one quickly obtains erroneous results or fouling of the metering device.

Many users settle and skim the liquid, using over- and under-baffles, the settler often being an integral part of the melter. Solids of larger particle sizes settle fairly rapidly but the fines and the black specks are difficult to remove in this manner.

In order to overcome their troubles, the users often filter the liquid. It is a precaution to mix sufficient lime with the sulfur to neutralize its acidity when the filtration is carried out. B. A. Axelrad and L. A. Nelson, Jr., have reported that the acid in brimstone is adsorbed on the solid gangue material and that

<sup>\*</sup> Present address : Arabian American Oil Co., New York, N. Y.

<sup>†</sup> Texas Gulf Sulphur Co., Worland, Wyo,

t Senior Fellow, Mellon Institute, Pittsburgh, Pa. (Multiple Fellowship sustained by Texas Gulf Sulphur Co., New York).

this gangue is more effective than lime (3).

Recently liquid brimstone has been shipped from the mines or from sour gas plants in insulated tank cars and trucks equipped with steam coils. Such sulfur should reach the user free of much contamination formerly acquired in shipment (1, 11). If the user can secure shipments of brimstone in this manner or free the liquid of contaminants by settling and/or filtration, there is no good reason why he can not meter the sulfur. As proof of this, results obtained on various types of meters with clean liquid sulfur are given in this paper along with some description of the metering device and the procedure followed. The types of meters investigated are listed in Table 1.

# Quantity Meters

Oscillating Piston. An Empire meter was tested for use with liquid sulfur. This meter for ½-in. pipe size was manufactured by the Pittsburgh Equitable Meter Co. The operating range was 1 to 7 gal./min. at pressures up to 150 lb./sq.in. The meter body was made of cast iron; the oscillating piston, of Ni-Resist. The meter was main-

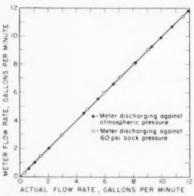


Fig. 1. Calibration of oscillating piston-type meter for metering liquid sulfur (Empire Meter).

tained at liquid-sulfur temperatures by placing it in a steam-jacketed vessel filled with liquid sulfur to such a level that all parts of the meter except the register were covered.

The flow of liquid is continuous and in one direction, through ports which are always fully open. The only moving part in the measuring chamber is the piston, which oscillates smoothly in a circular motion between the two plane surfaces of the chamber heads. The piston motion is transmitted by an enclosed train of gears to the register which is housed outside the meter casing.

Brimstone was pumped to the meter through steam-jacketed equipment so arranged that the flow rate and back pressure on the meter could be varied. A steam-

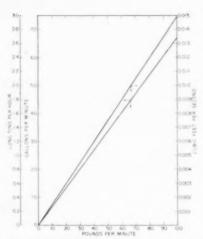


Fig. 2. Liquid sulfur flow rate. sp.gr. = 1.79.

jacketed diaphragm-type pressure gage was part of this equipment. Sulfur from the meter was run into a calibrated steamjacketed tank.

The meter register checked the calibrated tank to within 2% when the sulfur rate through the meter was in the range of 1 to 7 gal/min. In one series of experiments the meter discharged against no back pressure; in another series against 60 lb, sq.in. back pressure. At rates of less than 1 gal/min, the meter may read low; at rates above 7 gal./min, the pressure drop through ½-in, equipment is excessive. Results of the tests are shown in Figure 1. Figure 2 gives the flow in other units.

After six months of intermittent use and nearly half a million gallons of sulfur had been metered, tests indicated that the meter still measured the flow of brimstone accurately. However, the plaster of Paris which sealed the glass window to the register housing was broken, sulfur vapor had reached the interior of the register; and while the gears made of a white metal were not corroded, the brass gears were found to be coated with a heavy layer of copner sulfide.

The Buffalo Meter Co. has found that the single mutating piston-type meter, commonly called disc-type, has proved successful for the metering of liquid brimstone. Materials of construction have constituted the main problem in the building of this meter. Customers now have an option of cast iron, cast iron with a steam jacket, cast steel, or cast stainless steel for the outer casing. Cast iron is unsatisfactory for the internal working parts but the measuring piston is made of metal except for the ball in the center which is composed of hard carbon. Other factors that influence the operation of such a meter are simplicity, ruggedness of construction, number of moving parts, clearances to compensate

for the expansions of metals at the metering temperatures, and calibration. The meters are calibrated at the factory with a test liquid and compensated for the viscosity of the liquid sulfur at the metering temperature (4).

Measuring Tanks. The idea of using measuring tanks for liquid sulfur goes back to the oil industry where oil production has always been measured by determining the level of oil tanks. Measuring tanks have been used for metering large volumes of liquid sulfur for many years. Whether they could find use in measuring smaller volumes of liquid brimstone is not known.

The equipment consists of a vertical centrifugal pump with a capacity of 160 to 175 gal./min. which is maintained hot by operating under a liquid-sulfur surface. steel tank 6 ft. 53/4-in. diam. and 6 ft. high equipped with separate jacketed intake and discharge lines has an overflow box mounted on its top containing a swinging 1/2-hp. motor drives a reduction gate. A gear which opens and closes the intake and discharge valves. A two-way reversible switch, a timing device, two Mercoid switches (one on the overflow gate; the other on the valve mechanism), a counter arm and a graphic ammeter in series with the motor that drives the sulfur pump com-

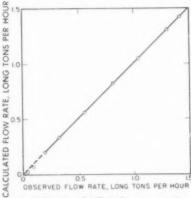


Fig. 3. Calibration of Hills-McCanna proportioning pump for metering sulfur.

plete the list of items required for opera-

The tanks are calibrated by weighing the volume of water at a known temperature required to fill the tank. The equivalent long tons of sulfur that the tank will hold are calculated from this water weight. Metering consists of counting the tanks filled and emptied per day.

Operation of these measuring tanks requires little attention. An attendant must start pumping the sulfur to be measured from the sump to the measuring tank. When the tank is full, the overflow or swinging gate Mercoid switch makes contact, starting the motor which operates the valve mechanism. It closes the inlet valve and then opens the outlet valve. The timing device holds the valves in this position until

the tank is empty. The discharged, measured sulfur runs by gravity to another sump. At the end of the timing period the valve-operating motor is started in reverse by the timing device through the second Mercoid switch. This time the discharge valve is closed and the inlet valve is opened. Operation continues until the attendant stops the sulfur pump.

Tanks filled are counted by the mechanical counter arm and checked by the points of maximum current on the graphic am-

meter chart.

Proportioning Piston Pump. Tests were made using a Hills-McCanna L.D.M.-16 two-cylinder alternate-stroke piston pump. The pump was driven by a 34-hp motor through a 48-to-1 reduction gear giving 37.3 strokes/min. for each piston. The diameter of the pistons was 2 in. and the piston stroke could be varied by setting an adjusting screw along a scale graduated from 1 to 24. A change in the setting of the adjusting screw did not change the piston stroke of each piston by the same amount. The pump cylinders were submerged in liquid sulfur and delivered sulfur to a steam-jacketed line.

With the adjusting screw set at various scale settings sulfur was collected for a period of 1 min. and weighed. For a sulfur flow of 0.2 to 1.4 long ton/hr, the observed sulfur delivery checked the calculated delivery fairly well (Fig. 3). With back pressure it was found that the actual flow figures were slightly lower than the calculated figures. This decrease in delivered volume is a linear function of the square root of the back pressure in pounds per square inch and ranged from 0.02 to 0.08 long ton of sulfur/hr. on the pump tested in the pressure range of 4 to 100 lb./sq.in. The pump had been in use for some time before these tests were made and it is possible that the pistons did not fit as tightly as when the pump was new. Since these tests were made the type pump used has become obsolete. Hills-McCanna Co. now manufactures a type pump assembly with jacketed cylin-ders and jacketed check valves.

For pumping small amounts of liquid sulfur at reproducible rates, H. O. Folkins, E. Miller, and H. Hennig developed a piston-type pump (6). One or more of a series of pistons of known diameter moved into a cylinder filled with liquid brimstone at 140° C. at a constant, known rate to

displace the liquid.

## Head Meters

Orifice Meters. Three orifice plates made of stainless steel and beveled on the downstream side were tested. The orifice diameter in these plates was ½-, ¾<sub>6</sub>-, and ¼ in., respectively. The plates were used in a 1-in. steam-jacketed pipe so that the orifice to pipe-diameter ratios were 0.119, 0.179, and 0.238, respectively. The differential taps were modified throat connections two-pipe diameters upstream and one-pipe diameter downstream. For throat connections the taps theoretically should have been placed one-pipe diameter upstream and 0.33-pipe diameter downstream (13).

Measuring differential sulfur pressures is a problem. In the past, with large sulfur flows, it has been done successfully by measuring the differential pressure of the two countercurrent air streams required to prevent sulfur from rising in the orifice taps. With this method a few bubbles of air per second are introduced into the sulfur main-line flow and a correction is made for the air introduced. For these tests

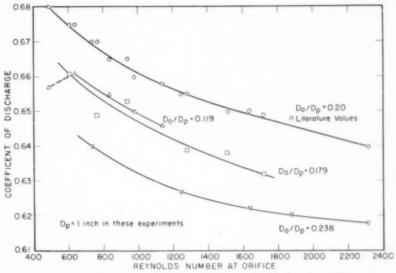


Fig. 4. Coefficient of discharge vs. Reynolds number for liquid sulfur through an orifice meter.

a special manometer was made to determine the differential pressure. Liquid sulfur was permitted to rise in the steam-heated legs of an inverted U tube. The legs were made of Pyrex glass scaled at the orifice taps and an overhead steel header with packing glands. The overhead header or manifold was fitted with two needle valves; through one compressed air could be introduced; through the other air could be vented to the atmosphere. By careful manipulation of the needle valves the rise of the sulfur in Pyrex glass legs of the inverted U tube could be controlled so that the differential pressure could be read as the pipe-line pressure was varied. Both Pyrex glass legs were surrounded with a steam jacket of steel, slotted front and back for observation of the sulfur level.

For each flow rate the differential pressure was determined and the sulfur delivery over a three- to five-minute period was collected and weighed. The sulfur volume was calculated from the sulfur density at the flowing temperature.

The coefficient of discharge was calcu-

lated from the formula:

$$V = \frac{CA_2\sqrt{2g\Delta H}}{\sqrt{1 - (A_2/A_1)^2}}$$

Calculated values found for the coefficient of discharge were compared with the values found in the literature (13) (Fig. 4). This work indicated that coefficients of discharge given in the literature can be applied to liquid sulfur with an average error of less than 3%.

An orifice meter with two Taylor force-balance transmitters has measured the flow of sulfur with a difference of less than 1% from the measured volume. The transmitter uses a diaphragm of tantalum. All other parts in contact with sulfur are made of stainless steel. The pressure is transmitted via the diaphragm to a Taylor aneroid manometer which actuates a recorder (14).

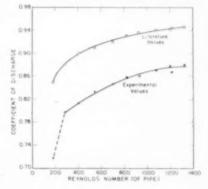
A. F. Benson, vice-president of the American Meter Co., has made the following statement (5):

On the Gulf Coast we have hundreds of meters measuring liquid sulfur. The method employed consists of bleeding air into the two gage lines at a pressure slightly above that of the liquid sulfur. The change in back pressure, caused by the differential across the orifice on the air emitting from the two gage lines causes the instrument to record the true differential across the orifice. As a result of this, the sulfur does not enter the orifice meter at all and consequently no corrosion of any kind takes place.

I. Bencowitz has developed a flowmeter (orifice) in which the difference in pressure is measured electrically, Small differences in pressure may be magnified electronically (12).

In the laboratory small quantities of liquid sulfur have been measured successfully with heated capillaries or fritted glass discs supplied by a reservoir under a constant pressure of nitrogen, Heated bellows pranps, driven at con-

Fig. 5. Coefficient of discharge vs. Reynolds number for liquid sulfur through a Venturi.



stant speed, have also delivered metered amounts of the liquid for laboratory use.

Venturi Meters. A 1-in. stainless steel Venturi meter with a ¼-in. diam. throat was purchased from the Republic Flow Meter Co. for tests with liquid sulfur. This meter was manufactured by the Simplex Valve and Meter Co.

The meter was maintained at liquid-sulfur temperature for these tests by being placed under the surface of a bath of liquid sulfur. Differential pressures were determined for sulfur tests by using the steamheated inverted type of U tube manometer described earlier in this paper.

The coefficients of discharge for sulfur were calculated for various rates of flow by the same formula used for the orifice meter. The coefficients of discharge for sulfur obtained from these observations and calculations are given in Figure 5 and are compared with values for the coefficients of discharge for Venturi meters as found in the literature (9).

Discharge coefficients for sulfur with this Simplex Valve and Meter Co.'s Venturi meter, calculated from observed data, ran as much as 18.5% lower than those found in the literature for the same Reynolds numbers, with an average of 9.9%.

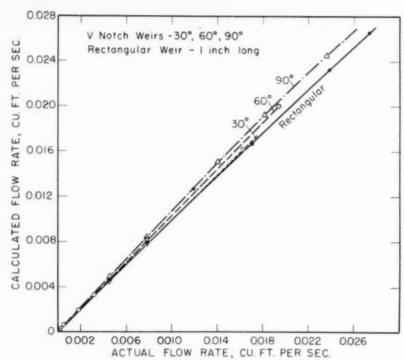


Fig. 7. Calibration curves for metering liquid sulfur with weirs.

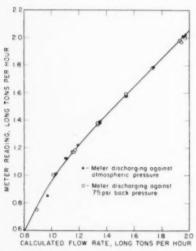


Fig. 6. Calibration of a Fischer and Porter rotameter for metering liquid sulfur.

# Area Meters

Rotameters. A Fischer Porter jackcted meter was graduated to read from 0.5 to 2.0 long tons of sulfur/hr. The length of the graduated scale from 0.5 to 1.0 long ton/hr. was 3/2 in. long while from 1.0 to 2.0 long tons/hr., it was 7½ in. long.

The tapered-metering tube in this instrument was 1½ in, in diam, at one end and 13%4 in, at the other end. It was a plain steel tube 14½ in, long. Two ¾ in, by 10½ in, vertical slots were cut from the

front and back of the tube to afford a means of determining the position of the float in the tube. The slots were covered with two heavy gauge glasses. Graduations were etched on the front gage glass.

A stainless steel Stabl-Vis float rode upon a stainless steel rod centered in the tube by means of spiders recessed into the top and bottom flanges of the meter. The rod was fastened to the spiders with nuts and it was found that due to a difference in the coefficient of expansion of plain and stainless steel these nuts should not be tightened as, upon heating with liquid sulfur, the rod might buckle and stop float movement.

Sulfur was pumped through the meter at a uniform rate of flow and the time for filling a calibrated steam-jacketed tank was observed. Tests were run with and without back pressure on the meter.

back pressure on the meter.

In the range of 1.0 to 2.0 long tons/hr, it will be seen from Figure 6 that the meter checks the calibrated tank to an average accuracy of about 2.5%. The meter was not reliable in the range of 0.5 to 1.0 long ton/hr. Thus while this meter has a 4-to-1 range, it is really accurate in only a 2-to-1 range. The slot in the tapered steel tube of this meter interfered with its sensitivity in the lower range.

Fischer and Porter Co. has installed a number of rotameters in this service and many of them have performed satisfactorily. Unfortunately, dilute sulfuric acid formed from the moisture picked up by the sulfur in transit or in stockpiles, has caused severe corrosion in some instances. In addition, plugging of some meters has occurred because of the dirt and coke present in the sulfur as a result of handling and the attack of acid on organic matter in the brimstone. Then, too, where the pressure in the steam jacket has been uncontrolled, high temperatures have raised the viscosity

of the sulfur to the point where the meter is no longer reliable. At present this company will sell a meter for this service only if the customer will accept responsibility for plugging and corrosion (7).

# Weirs

V-notch weirs, 30, 60, and 90°, respectively, were tested with liquid sulfur along with a 1-in. length rectangular weir. The weirs were cut from a sheet of ½½-in, thick stainless steel. The maximum height of each weir was 3 in. Fouling of the edges by organic matter caused some difficulty. Beveling of some of the weirs in later work indicated that it produced only a slight difference in results.

The weir plate was mounted at one end of a rectangular steam-jacketed tank 24 in. long, 12 in. wide and 12 in. deep. Upstream, 14 in. from the weir plate, a baffle was welded across the tank 1 in. from the bottom, and 10 in. from the weir plate a hook gage was mounted on the side of the tank. The baffle insured a quiet liquid surface in the region of the hook gage. A vernier scale on the hook gage permitted reading the liquid head to an accuracy of 0.01 in.

For small flows the sulfur was collected for a definite time period and weighed; for larger flows the time required to fill a calibrated tank was observed. Results calculated from these observations for sulfur are given in Figure 7. Also in Figure 7 the observed values for various heads of sulfur are compared with values calculated by the formula for water given by Grebe for V-notch weirs and the formula of Francis for rectangular weirs (10).

A 30° V-notch weir measured the flow with an accuracy of 0.4%. However, the 60° and 90° weirs deviated by average percentages of 6.9 and 7.6, respectively. For a rectangular weir the observed flow came within an average of 1.7% of the calibrated tank.

# Comment

Users of sulfur have always experienced difficulty in metering the flow of this element as a liquid. The evidence presented in this article shows that liquid brimstone, free of acid and suspended matter, may be metered with the meters commonly used for other liquids provided the instruments are maintained in the temperature range of 125° to 150° C.

# Acknowledgments

The authors gratefully thank Texas Gulf Sulphur Co. for supporting the work and for permission to publish the results. W. W. Duecker of Texas Gulf Sulphur Co. and W. A. Hamor of Mellon Institute kindly aided in the preparation of this manuscript. G. P. Giusti, Mellon Institute, checked the calculations.

## Notation

 $A_1 = \text{cross-sectional}$  area of pipe,

 $A_2 = \text{cross-sectional area of orifice,}$ sq.ft,

C = coefficient of discharge

 $D_o = \text{diam. of orifice, ft.}$ 

 $D_p = \text{diam. of pipe, ft.}$ 

 $D_2 = \text{diam. of Venturi, ft.}$ 

 $\tilde{H}$  = head on weir, ft. of sulfur

 $\Delta H$  = pressure difference across orifice or Venturi, ft. of sulfur

L = length of weir crest, ft.

V = volume of sulfur, cu.ft.

a = angle of V -notch weir

s = sp.gr. of liquid sulfur

 $\frac{\mu}{\mu_{-}}$  = relative viscosity

# Literature Cited

- Anonymous, Chem. Eng., 53, 111 (September, 1946).
- Anonymous, "Sulphur—An Essential to Industry and Agriculture," Texas Gulf Sulphur Co., New York (1940)
- Axelrad, B. A., and Nelson, L. A., Jr., Ind. Eng. Chem., 42, 2212 (1950).
- Barrett, H. F., Correspondence with J. R. West.
- Benson, A. F., Correspondence with J. R. West.
- Folkins, H. O., Miller, E., and Hennig, H., Ind. Eng. Chem., 42, 2202 (1950).
- Larson, J. O., Correspondence with J. R. West.

- Lee, J. A., Chem. Eng., 55, 119 (April, 1948).
- Perry, J. H., "Chemical Engineers' Handbook," 3rd ed., p. 407, Mc-Graw-Hill Book Co., Inc., New York (1950).

10. Perry, J. H., ibid., pp. 408-10.

 Sawyer, F. G., Hader, R. N., Herndon, L. K., and Morningstar, E., Ind. Eng. Chem., 42, 1938 (1950).

 Bencowitz, I., U. S. Patent 2,103,741 (Dec. 28, 1937).

- Walker, W. H., Lewis, W. K., Mc-Adams, W. H., and Gilliland, E. R., "Principles of Chemical Engineering," pp. 60-1, 3rd ed., McGraw-Hill Book Co., Inc., New York (1937).
- Warren, I. E., Taylor Technology, 3, No. 2, p. 7 (1950).
- West, J. R., Chem. Eng., 53, 225 (October, 1946).

# Discussion

A. L. Landesman (Fischer & Porter Co., Hatboro, Pa.): What were the properties of the sulfur you used in your test? You mentioned at one point, that certain sulfur was free of suspended matter and contained no moisture or acidity. Later you dwelt vaguely on this suspended matter. Just what kind of sulfur did you use?

J. R. West: The sulfur used in these tests was as free as possible from the impurities which I mentioned. The sulfur came directly from the mines and contained but a small quantity of organic matter and no moisture to start corrosion.

A. L. Landesman: How do you get rid of this organic matter when you encounter it?

J. R. West: Freeing sulfur of organic matter has always been a problem. As I said, filtration is one effective means that can be used, where the organic material is undissolved. That removes both ash and organic matter if they exist in large enough particles. The present practice, I believe, is to use a filter aid with the liquid sulfur and that has proved rather effective. If the organic matter is dissolved, then adsorption on a solid adsorbent, followed by filtration may be applied.

A. L. Landesman: At an installation where our equipment is used to meter molten sulfur, solid impurities were recently encountered in the sulfur. Although filtration was used, some fine particles did pass the filter and agglomerate in various parts of the meter, making it inoperative. Incomplete analysis of these masses showed the presence of iron sulfide and potassium sulfate, the latter apparently from neutralization. Can we also expect to find arsenic compounds in these particles?

J. R. West: No, you will find no arsenic, selenium, or tellurium in any Gulf Coast sulfur produced in the U. S. Your iron sulfide presumably came from some corrosion or perhaps from being picked up in shipment. Sulfur, as it leaves the mine, is 99.5 to 99.8% pure, but often in shipment in the solid form, particularly, picks up a lot of impurities.

A. L. Landesman: I might add for general information that we have found for most industrial service that Carpenter 20 is the best anticorrosive material.

J. R. West: I believe that many users prefer some type of stainless steel in their meters.

A. L. Landesman: Dr. West, permit me to elaborate on the statement from my company which you injected in your paper. Two factors, in addition to complete removal of solids, are of concern in the application of any equipment for metering molten sulfur.

Because sulfur has only one tremendous increase in viscosity and that is above about 310° F., it is necessary to control carefully the temperature in the meter. Between 248° and 302° F. the viscosity changes from 12 to 7 centipoises.

Frequently, high concentrations of corrosive acids are present in sulfur which has been improperly stored. Although Carpenter 20 is highly acid resistant, life of the equipment can be lengthened by protection of the sulfur from the elements, from bacterial oxidation caused by contact with soil, and/or by neutralization of free acids. High accuracy of measurement also will be preserved.

My company has developed a completely jacketed variable area flow meter which will operate successfully if the user recognizes his significant responsibility to provide the meter with clean, acid-free, low-viscosity molten sulfur.

(Presented at A.I.Ch.E. Rochester (N. )',) Meeting.)

# CORRECTION

In Practical Thermodynamics, by Brown and Sliepcevich (see October, 1952, page 493), typographical errors occurred in three equations, namely, (16), (19), and (20) on page 496. These equations should read as follows:

$$(G_e - G_i)_T + mg(Z_e - Z_i) + \frac{m}{2}$$

$$(v_e^2 - v_i^2) + NFE_e - NFE_i = -w_{res}$$

$$-w - (lw)_a = \Delta U - T_o \Delta S + \frac{m\Delta(v^2)}{2}$$

$$-w - (lw)_a + P_o \Delta V = -w_{uxeful} = \Delta U - T_o \Delta S + P_o \Delta V + mg\Delta Z + \frac{m\Delta(v^2)}{2}$$

$$(20)$$

# Flash Vaporization

Analysis of Fluid Mechanical and Mass-Transfer Problems

R. R. Hughes, H. D. Evans, and C. V. Sternling

Shell Development Company, Emeryville, California

In all flashers and evaporators, the mechanical separation of vapor from its entrained liquid is a major feature. In vacuum operations, it is especially significant because of the high velocities normally used. This paper discusses the general concepts of liquid atomization, drop separation, and flashing efficiency and their relation to the design of the vaporizer, the transfer lines, and the separator. The concepts are developed semiquantitatively as a guide to further development and design work on these flashing processes.

A MAJOR industrial problem is the separation of materials of varying volatility. One useful solution, especially for materials covering a wide range in volatility, is flash vaporization. An important example of this process and the reason for this study of it is the vacuum flashing of hydrocarbon residues to produce catalytic-cracker feed stock. However, these methods of analysis can be applied to any flash vaporization, such as the purification of fatty acids, glycerine, etc., and their separation from by-product salts.

To provide a high degree of separation, flash vaporization is often carried out under vacuum, at pressures as low as 5 to 10 mm. Hg. At the low pressures and the high temperatures used, flows through the separator are often on the order of 1000 cu.ft./sec. or higher. With such flows, separation of the liquid entrained in the vapor is often difficult, since the resulting high velocities break up the liquid into fine droplets.

While separation is often difficult, usually it is also extremely important. For example, in the vacuum flashing of hydrocarbon residues, the overhead is normally used for catalytic cracking.

Any entrainment in this overhead product may poison the catalyst and reduce catalyst life. Similarly, in the purification of a volatile product, entrainment may contaminate the product to the point where it does not meet specifications and cannot be sold. If the bottoms is the desired product, severe entrainment results in a loss of useful material.

# Process Flow Sheet

Fundamentally, flash vaporization consists of heating a liquid feed, partially flashing the feed by the heating and a reduction of pressure, separating the liquid from the vapor, and cooling the products. The process can be represented schematically by the flow sheet of Figure 1. After being preheated by heat exchange with the product streams, the feed is heated in the fur-Then it proceeds, through a transfer line, to the flash chamber or separator. The overhead product is removed through a condenser, where the condensed product is separated from any fixed gases present. These are then removed through ejectors to maintain the vacuum in the system. This second separation in the usually not a problem, since the fixed gases are normally very small in amount. The are normally very small in amount. bottoms product is usually removed directly through exchangers or coolers to storage or

Within the limitations of this flow

sheet, the desired products can be obtained by various combinations of process pressures and temperatures and various types of furnaces and separators. Fundamentally, the choice of a given path and given equipment depends solely on a balance of the value of product purity and yield against the cost of equipment and operations. For example, two cases similar in all respects save total flow may require entirely different furnace-exit pressures for the optimum plant design. Use of a standardized sequence of pressures and temperatures or a standardized furnace design is not economically sound and may lead to insoluble separation problems.

# General Aspects of the Problem

Before specific details arising from the equipment to be used are discussed, the general factors entering into any flash vaporization should be reviewed.

Thermodynamic Properties. evaluate a flash vaporization, the thermodynamic properties of the material to be flashed must be known. Figure 2 shows a typical chart of these properties for a hydrocarbon residue. Similar relationships hold for other cases, although the presence of solids or of salts in solution may considerably change the relative positions of the lines. The chart allows the evaluation of the specific enthalpy, specific volume, and per cent vaporized at any given pressure and temperature for the mixture, as long as (1) no gross separation occurs between the liquid and the vapor and (2) complete mass-transfer and temperature

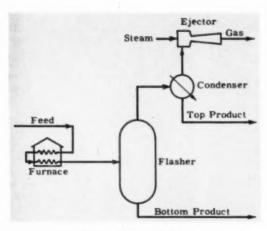


Fig. 1. Typical vacuum flashing unit.

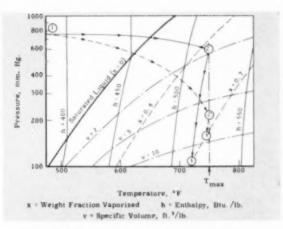


Fig. 2. Typical thermodynamic chart for hydrocarbon residues.

equilibrium exists between the liquid and the vapor. From this chart, the need for reaching low pressures and high temperatures to obtain large fractions of total feed overhead is evident. The extent to which these conditions can be met depends on the other factors discussed below.

Atomization. Since the major purpose of this process is the mechanical separation of liquid from a gas stream, the dispersion characteristics of the mixture are very important. Each mechanism of dispersion and atomization will be discussed below in connection with the particular part of the process where it may occur. However, in general, it can be considered that high velocities will increase atomization, because of the higher kinetic energy available.

Pressure Requirements. It seems obvious for vacuum operations that provision must be made for absorbing considerable pressure drop between the liquid feed point and the flasher. However, provision for this pressure drop without having undesirable atomization at some point in the apparatus is often quite difficult.

A lower limit on the pressure attainable in the flash chamber results from the method used in maintaining the vacuum, the vapor pressure of the condensed overhead, and the amount of fixed gases released from solution or produced by degradation in the process.

Heat and Temperature Effects. To provide the desired high temperatures, a considerable heat input is required. The velocities and tube sizes in the furnace must be such as to produce the desired temperature rise in as small a total volume as possible. At the same time large temperature gradients in the fluid may result in excessive temperatures in parts of the fluid near the tube walls; velocities therefore must be sufficient to minimize these gradients, at least at the high-temperature end of the furnace. Even if all hot spots are eliminated, the temperature sensitivity of the fluid may depend on its residence time at high temperatures, thus requiring high average velocities if high temperatures are desired. It is customary to set some maximum allowable temperature for a given design without regard to velocities or residence time. This may lead, at times, to an uneconomical choice between two given alternative designs, although the complexity of the whole problem may demand that some variables be fixed.

After leaving the furnace, the process is essentially adiabatic. As seen in Figure 2, a pressure drop downstream of the furnace, following a constant-enthalpy (h) line, will result in considerable cooling to provide the latent heat for the additional vaporization occurring.

Another feature of the temperaturetime relationships may be the effect of fixed gas production. A temperature increase to increase the degree of flashing may result in considerably higher fixed gas production. As a result, the given ejector system may become overloaded, thus increasing the flashing pressure and actually reducing the depth of flashing.

Equipment Requirements. The physical limitations of the equipment are often of controlling importance in flash vaporization. Although, as indicated above, there is a lower limit to the flashing pressure, dictated by ejector and condenser design, adverse equipment size necessary to prevent excessive atomization may actually require operation at a considerably higher flashing pressure. Some idea of this effect can be obtained by studying the specific volume lines on the thermodynamic chart (Figure 2). For a given mass flow, volumetric flow is proportional to specific volume, so that a doubling of specific volume would probably require a doubling of the flow area. While this increase in equipment size may be justified by the higher degree of flashing, each case requires an economic evaluation.

Additional equipment requirements may be those dictated by mechanical strength, corrosion, and mechanical wear, or erosion. High velocities probably should be avoided at certain points where erosion may be severe. In addition, where high velocities are inevitable, as in the separator, care should be taken to keep supporting members out of the main stream, to prevent their rapid erosion.

Mass Transfer. An increase (Fig. 2) in temperature or a decrease in pressure results in further volatilization. This, in turn, increases the equilibrium concentration of heavy components in the vapor. The maximum amount of vapor attainable at a given pressure and tem-

perature is usually desired. To attain this, good contact must be provided between the remaining liquid and the vapor released in the early stages of vaporization, so that some of the heavy material can be stripped from the liquid by the vapor. Accordingly, a fine dispersion just upstream of the separator has advantages in over-all yield, in spite of the resulting difficulties with entrainment separation. After separation occurs, good contacting is of course impossible, and so further volatilization proceeds with no assisting stripping action.

The lack of good mass transfer in the furnace may result in abnormal concentration of heavy components in the liquid in contact with the wall. As this is also the region of highest temperature, these heavy components, which are often the most susceptible to degradation, are subjected to the most extreme conditions. Moreover, the concentration of heavy components probably results in high viscosities, thus increasing their residence time.

The Separation. Once the necessary heat and flashing have been obtained in the furnace and transfer lines, the two phases must be separated in some type of separating device. Generally, the separation ability of the device for given flow and pressure conditions may be estimated in terms of some representative drop diameter such as the minimum separable drop diameter proposed by Rosin, Rammler and Intelman (27). However, the actual separation efficiency as measured by the per cent of total liquid separated will depend, not only on the separation ability of the unit, but also on the size distribution of the droplets to be separated. As mentioned above, the droplet sizes may be reduced considerably by high velocities. Therefore, although high transfer-line velocities may be favorable in many respects. they will be detrimental if atomization puts a severe burden on the separating system which will result in excessive entrainment, excessive pressure drop, excessive separator costs, or reduction in overhead yields.

Summary of the Problem. In summarizing, it can be stated that high velocities in the furnace and transfer lines are desirable in that they require smaller equipment sizes, permit more favorable temperature gradients in the furnace, thus minimizing harm to heat-sensitive materials, and, finally, by creating finely divided droplets of liquid in gas, promote contacting between vapor and liquid. However, on the debit side, these high velocities may increase erosion and corrosion and, more important, may create drop sizes so small that they can-

not easily be separated without great equipment expense and possible reduction in throughput.

The problem in designing a vacuum flasher system is to arrive at the optimum combination of all the foregoing factors. However, in most instances basic methods for estimating flow patterns, pressure drop, dispersion, and phase separation for systems such as these, although very necessary, are poorly developed. In the following section, some of these fluid-mechanical and mass-transfer problems are analyzed, and possible directions for future study and experiment are indicated for the two principal sections of the flasher system: (1) the furnace and transfer lines and (2) the separator.

#### Furnace and Transfer Lines

Types of Flow. Flow conditions in the furnace tubes and transfer lines have a major effect on both the ease of entrainment separation and the mass transfer at downstream positions. This is due to the importance of flow conditions in determining the initial degree of breakup of the liquid and its subsequent coalescence and redispersion. As an introduction to this problem, the types of two-phase flow that have been described by various experimenters may be considered.

Figure 3 shows limits of stability for various types of two-phase flow. It is based on the data of Kosterin (13), but other experimenters have reported similar results (4, 11). The particular case shown is for

air and water in a horizontal 4-in. tube. The transitions are plotted against the volumetric flow fraction of gas and the superficial velocity of the mixture. Kosterin found that this method of plotting partially eliminates the effect of tube size, at least for the higher velocity transitions. velocities, the flow is stratified, exhibiting a separate water channel along the bottom with the gas moving in the upper part of the tube. At intermediate velocities, various types of slugging flow occur. The main effect of tube diameter seems to be in shifting this transition between stratified and slug flow. For smaller tubes this transition occurs at lower velocities, thus increasing the range of velocities over which slugging occurs. At higher velocities the effect of the flow fraction of gas becomes significant. At flows with less than 80% gas by volume, which might correspond to less than 0.1% gas by weight, the mixture flows as a froth with the gas dispersed throughout the liquid phase as bubbles of various sizes. There is at present no evidence for a further change in flow regime at these low gas concentrations as the velocity is further increased. For flows at greater than about 10 to 50 it./sec. and with more than 85% gas by volume a differ-ent type of flow occurs. Under these conditions, the liquid is thrown to the wall and flows as an annular film through which the gas moves as a more or less pure phase. As the velocity is increased, the available evidence seems to indicate that more and more of the liquid is entrained into the center. Finally, when the velocity exceeds perhaps 300 ft./sec., observations reported by Stroebe, et al. (35), indicate the occur-rence of dispersed flow where most of the liquid is carried by the gas in the form of fine droplets.

By assuming that the diagram of Figure 3 applies to the proposed flasher operation, an indication can be obtained of the types of flow to be expected at various positions in the furnace tubes and transfer lines. At the entrance to the furnace, the liquid flows

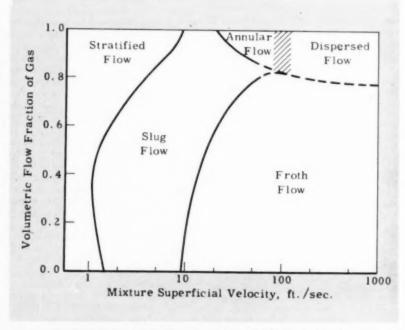


Fig. 3. Limits of various two-phase-flow regimes (13); air-water in 4-in. pipe.

as a single phase. Later, as vaporization begins, the velocities are usually low, and stratified flow occurs. This has been shown by various model tests and also by studies of corrosion patterns in furnace tubes. It may be desirable to know how long stratified flow persists so that its effects on increased corrosion, unequal distribution of liquid in parallel pipes, and higher liquid

residence time may be properly evaluated. Nearer the exit of the furnace, the velocities are higher, because more material has been gasified. As a result of this high velocity, the pressure gradient is high and the vaporization is consequently accelerated. Attempts are usually made to keep this velocity down by increasing the flow area near the furnace exit, but it is impractical to operate at less than about 100 to 400 Thus dispersed flow is usually established some distance from the exit. The transfer lines may operate at a some-what lower velocity, but not low enough to be outside the dispersed-flow range. Al-though operation in this region aggravates problem of entrainment removal, offers advantages of good contacting between the liquid and the vapor and of reduced liquid residence time in the furnace tubes, as discussed above.

# Prediction of Drop Sizes Created in Transfer Lines and Cyclones

Mugele and Evans (21) have presented a method for estimating the distribution of drop sizes in various spraying devices in terms of the maximum drop diameter,  $D_m$ , and two dimensionless parameters, a and  $\delta$ , as follows:

$$\frac{dv'}{dy} = \frac{\delta}{\sqrt{\pi}} e^{-t^2y^2} \qquad (1)$$

where

$$y = \ln \frac{aD}{D_m - D}$$
,

This equation is plotted in Figure 4 for a range of experimental values of a and δ. These data cover a rather wide range of atomizing-nozzle types, and it is probable that for breakup due to flow in pipes the range of a and δ would be considerably narrower. Clay (6) presents data for breakup due to flow in pipes of a liquid-liquid system, and Wetzel (37), Nukiyama and Tanasawa (22) and Lewis, et al. (17), for breakup due to atomization in venturi throats. The mechanism of breakup for these devices should be similar to the mechanism for breakup of a vapor-liquid system in pipe flow; so an examination of these data could lead to a method for prediction of drop-size distributions created in furnaces and transfer lines. Of course, additional experimental measurements of drop sizes created in pipe flow would be extremely helpful.

Numerous authors, such as Merrington and Richardson  $(2\theta)$ , Hinze (8), etc., have studied the breakup of freely falling droplets in gases, and Lane (15) has studied the breakup of drops exposed to a sudden blast of air. Both Hinze and Lane found that the maximum stable drop diameter,  $D_{\rm m}$ , could be estimated in terms of a critical Weber number (the ratio of inertia forces to surface forces):

$$\frac{\rho_o V^2 D_m}{g_c \sigma} = W c_c. \qquad (2)$$

The numerical value of We<sub>e</sub> is different for different types of breakup. In Figure 5 there is illustrated, in

this connection, a possible mechanism leading to dispersed flow in pipes. Gas moving past the annular liquid film, and/ or pipe roughness create waves at the interface, the tips of which may be broken off and dispersed into the central portion of the pipe. Some of these dispersed droplets make their way back to the wall and recoalesce there. The final drop-size distribution is determined by the equilibrium between drops leaving and arriving at the wall. It can readily be seen from the force picture shown in Figure 5 that this mechanism shows again that drop sizes are determined by balance between the inertia force,  $F_4$ , and the surface force,  $F_2$ , and, therefore, that the Weber-number concept should apply, Since the velocity past the wave is proportional to the average velocity in the tubes, this Weber number can be calculated as:

$$F_1 \propto D_t^2 \rho_g V_t^2 / g_e$$

$$F_2 \propto D_t \sigma$$

$$\frac{F_1}{F_2} \propto \frac{\rho_g V_t^2 D_t}{g_e \sigma} \equiv W e_t$$
(3)

where  $D_t$  is the particular value of  $D_m$ for the tube. A glance at this equation shows the desirability of keeping transfer-line velocity low to minimize atomization.

Turbulence in the main stream might also influence breakup and, conversely, might increase particle size by collisions resulting in coalescence. Again, however, the same balance of forces would exist, and, since turbulent

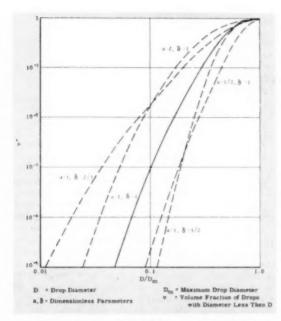


Fig. 4. Typical drop-size distributions (21) [Equation (1)].

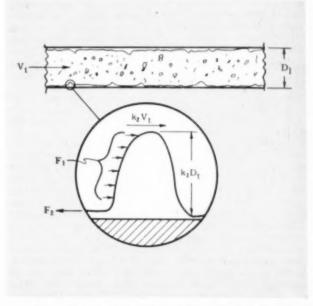


Fig. 5. Schematic picture of dispersed flow of liquids in gases.

fluctuations are proportional to mainstream velocities, Equation (3) should apply. Lapple (25) indicates that increased gas density and increased velocity each result in an increase in entrainment for cyclone-type separators. As discussed below, this could be interpreted as a decrease in entrainment size, thus supporting the foregoing Webernumber concept.

The exact value of  $We_t$  undoubtedly depends upon a number of other variables. By dimensional analysis, it can be shown that for straight pipes:

$$We_t = func\left(Re_t, \frac{D_t}{D_L}, \frac{\rho_\theta}{\rho_L}, \frac{\mu_\theta}{\mu_L}, x, \frac{D_L}{k}\right) \tag{4}$$

Data of Clay (6) for breakup in pipe flow and data cited above for venturi atomizers should again be useful in evaluating the effect of some of these groups. However, a great deal of additional experimental data are required to permit reliable estimates of  $D_{tr}$ .

These considerations have merely indicated methods for estimating the equilibrium dispersion size. Of nearly equal importance is the length of pipe required to establish this equilibrium. For example, the fine dispersion resulting from the use of a high velocity at the furnace exit can be tolerated if a sufficient length of low-velocity transfer line is used to permit the coalescence of the fine mist and its redispersion to a larger equilibrium drop size. Final quantitative evaluation of this effect must await additional experimental data of the type presented by Alexander and Coldren (1). However, some idea of the length of pipe required to reach a new equilibrium state can be obtained from the data of these authors. They found that from 50 to 100 pipe diameters are required for the deposition on the pipe walls of 90 to 98% of the dispersed liquid. Unfortunately, reliance upon this effect in the design of a new unit will be risky until confirming evidence becomes available.

It would appear profitable to make some experiments for the purpose of finding a design that would absorb a large pressure drop while preventing excessive atomization. This would permit use of small furnace tubes, short transfer lines, and low flasher pressures. For example, orifices, or similar contractions, inserted in a transfer line might absorb a large pressure drop with little additional drop breakup if the postulated mechanism of breakup from the pipe walls is correct. On the other hand, if breakup is due to the turbulence of the main stream, these insertions might aggravate the atomization. The effectiveness of these insertions would of course also depend on the rate of

coalescence and redispersion from the walls. The actual facts can only be determined experimentally.

# Pressure Drop in Two-phase Flow in Furnace and Transfer Line

Because of the high velocities involved in dispersed flow, compressibility effects are quite marked. By the usual derivation, given in most textbooks (7), the limiting velocity in an adiabatic, constant cross-section flow is found to be the acoustic velocity:

$$V_{a} = \sqrt{g_{e^{K}} \left(\frac{\partial p}{\partial \rho}\right)_{T}}$$
 (5)

where  $\kappa = \text{ratio of specific heats, } C_p/C_v$ For two-phase flow, both k and the derivative  $(\partial p/\partial \rho)_T$  should be evaluated for the mixture as actually flowing. This has been done for water by Allen (2) and Schweppe (30). If the assumptions of no slip and complete equilibrium between liquid and gas hold, these properties can be evaluated from the thermodynamic chart of Figure 2. This leads to the calculation of a critical velocity, V<sub>o</sub>. As this critical velocity is approached, both slip and nonequilibrium result, since the rate of pressure drop becomes extremely high. By analogy with single-phase compressible flow, attempts to exceed this critical velocity should result in pseudoexpansion and shock waves at the tube exit. This would require an infinite mass-transfer rate to maintain equilibrium, which is obviously impossible. To promote masstransfer equilibrium, it is probably desirable to design transfer lines so that flow velocities do not exceed this first critical, Ve.

As slip and nonequilibrium are both allowed for,  $V_a$  increases, although eventually it decreases if sufficient slip occurs. The maximum value occurs with no flashing at all, when the critical velocity, for the gas alone, is the usual acoustic velocity or, for a perfect gas:

$$V_g = \sqrt{g_{e} \kappa_g \frac{RT}{M_g}} \tag{6}$$

It should be noted that the acoustic velocity in heavy hydrocarbon vapors, even at the high flash temperatures generally employed, is relatively low, 300 to 500 ft./sec., because of their high molecular weight. Any attempt to exceed the acoustic velocity by increasing the pumping pressure merely increases the pressure and density on the system upstream of the critical section. The excess pressure drop is dissipated in expansion and shock waves downstream of the critical section. The intense atomization suffered by drops in passing through shock waves, as found by Lane (15) and

others, suggests that it is desirable to avoid these shocks.

For the actual pressure-drop calculations, experimental data are required. At the moment there are correlations of Lockhart and Martinelli (19) and the work of Bergelin (4, 5). Since these experimenters have worked only with the lower velocities and small diameters, use of their correlations involves a considerable extrapolation. Experimental work with dispersed flow at high velocities in large tubes is badly needed. It is possible that some help might be obtained by comparing this flow with fluidized transport of solids, which is mechanically quite similar.

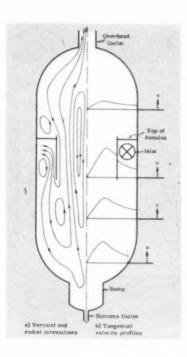
In addition to the pressure drop caused by wall friction, allowance must be made for the effects of acceleration and the pressure drops in fittings and in expansions and contractions. With proper inclusion of the liquid in the kinetic head terms, it might be safe to use the usual handbook formulas (23). Errors are introduced here, however, by inability to estimate accurately the slip between liquid and gas, so that experimental confirmation is required.

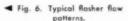
# The Separator

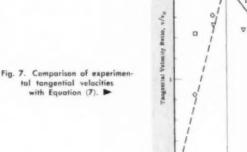
The finely dispersed liquid resulting from furnace and transfer-line conditions must now be separated mechanically. Of the many types of separators available (25), settling chambers, knockout boxes, filters, and electrical precipitators can be ruled out as too costly or unusable where liquid product is recovered in large amounts. Scrubbers-either spray chambers or contacting plates-are probably useful and should be studied but will not be considered here. Cyclones are widely used for flash vaporization and are the major subject of this paper. Impingement separators can sometimes be analyzed along the same lines as cyclones but at other times can be handled only by experimental measurements.

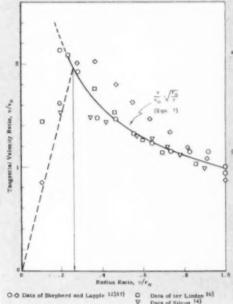
In order properly to design a cyclone separator, it is necessary to be able to predict its pressure drop, mass-transfer efficiency, and ability to separate liquid from vapor. In general, correlations are not available from which these quantities can be reliably estimated for typical liquid-vapor separations such as vacuum flashing. Even the available correlations of pressure drop and separation ability of gas-solid separators are somewhat limited in nature. It has been the custom to design these separators empirically based on previous experience with similar units. Often, if conditions are appreciably changed from design to design, this may lead to poor and/or uneconomical design of the unit.

Because of the widespread use and importance of cyclone separators for









gas-solid and gas-liquid separations and, more recently, for liquid-liquid and liquid-solid separations, there is a real need for sound, consistent methods of estimating performance characteristics. A fundamental analysis, based on the laws of fluid mechanics and mass transfer and on experimental knowledge concerning flow patterns and drop sizes, should lead to reliable methods of predicting pressure drop, separation ability, and mass transfer for cyclones.

The following sections review various aspects of the problem, point out how they may affect the performance of the unit, and suggest possible approaches which may be useful in arriving at final consistent methods for estimating cyclone performance.

Cyclone Flow Patterns. As a basis for solving the problem, an understanding of flow patterns and velocity profiles inside the separator is essential. Figure 6 shows typical radial stream lines and tangential velocity profiles for one commonly used type of vacuum flasher. Other flasher designs would give similar patterns although the strength of the various eddies depends on inlet velocities and relative dimensions of the inlet, the inner and outer cylinder, and the closure. Many authors (32-34, 36) have measured tangential velocity profiles inside cyclone-type units, and most of these data conform approximately to the equation proposed by Shepherd and Lapple (32):

$$v = v_o \sqrt{r_o/r} \tag{7}$$

where v and r are, respectively, the

tangential velocity and radius at a given point and  $v_o$  is the value of v obtained by extrapolating to the cyclone wall,  $r = r_o$ . This, of course, leaves out the semilaminar layers near the walls, which are negligible in industrial-sized cyclones.

In Figure 7, representative data (32-34, 36) are plotted as  $v/v_o$  vs.  $r/r_o$ . It is seen that Equation (7) holds outside of a maximum velocity point,  $r_m$ , which is somewhat less than the inner cylinder radius. The decrease in velocity inside this point is to be expected since viscous effects become more and more important near the axis, and wheel-like motion results.

Since separation occurs entirely in the region where Equation (7) holds,  $v_o$ becomes a convenient description of the entire velocity field for use in predicting cyclone performance. By angular momentum considerations, vo must be related to the inlet velocity, Vin. However, the data mentioned above show that the ratio of  $v_o$  to  $V_{in}$  may be greater or less than unity depending on the cyclone design. It is very likely that angular momentum relations across the cyclone inlet could be correlated in a manner similar to the correlation of linear momentum relations (i.e., pressure drop) for expansion and contraction in straight pipes.

Effect of Eddies on Performance. The existence of a strong centrifugal field creates a number of eddies as shown in Figure 6. Some of these eddies are helpful and others harmful to the performance of the unit. There is

usually an eddy near the inlet resulting from the fact that the semilaminar film at the roof of the annulus has a radial pressure gradient superimposed on it while the corresponding tangential velocities are slowed down by skin friction, Accordingly, an internal flow up across the roof of the cyclone and down the outer wall of the inner cylinder results. This eddy is strongest for small-diameter cyclones and may result in excessive entrainment from the unit, owing to sweeping of liquid across the roof and down the inner cylinder, where it is reentrained from the bottom. Experimental evidence for this type of entrainment has been reported by Pollack and Work (26).

For the same reason there is an internal downward flow along the closure wall resulting in a toroidal eddy somewhere beneath the inner cylinder. This eddy may be beneficial since it acts to sweep the liquid down the wall and into the sump. However, the rapid turn upwards near the axis may be responsible for entrainment if too high a liquid level is maintained in the cyclone.

An even stronger radial pressure gradient exists in the inner cylinder. Since the centrifugal field in the upper part of the flasher is rather weak, this gradient sets up a strong downward flow along the axis. The resulting eddy is the major source of pressure drop for the unit. Elimination of this eddy, with a corresponding reduction in pressure drop, can be achieved by making the gas flow out near the wall. For example, in Schneider's pressure-reduction device

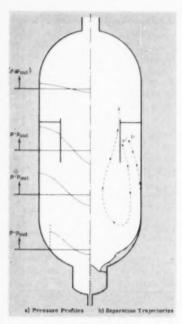


Fig. B. Typical flasher.

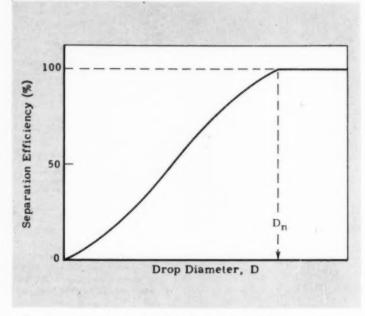


Fig. 9. Separation efficiencies of single-sized drops.

(29) the exit from the inner cylinder is nearly filled by a solid cone, forcing the gas outward. Here such a pressure-reduction device is impractical since it would need a diameter two or three times that of the cyclone. However, such ideas as tangential outlets, etc., may be worth while and deserve experimentation.

**Pressure Profiles.** Typical pressure profiles accompanying these flow patterns are shown in Figure 8. Data of this type have been presented by Shepherd and Lapple (32). However, if the radial velocity is negligible, they can readily be calculated as a function of radius using experimental or calculated tangential velocities [Equation (7)] by integration of the following equation,

$$\frac{dh}{dr} = \frac{\rho_g v^2}{g_c r} \tag{8}$$

In the annular space the centrifugal field results in a slight pressure decrease toward the axis. This decrease becomes accentuated in the turnaround region and is even stronger inside the inner cylinder. Notice that there is a finite difference in pressure across the inner cylinder wall. This is due to the angular momentum required to support the large eddy in the center. While the tangential velocities have weakened in the upper cylinder, there is still some pressure gradient which does not smooth out until some distance downstream of the actual exit.

The fairly strong pressure gradient in the turnaround can cause an undesirable effect in the sump. In small cyclones, in

particular, the difference in pressure, which may correspond to several inches of liquid, can support a jet of liquid near the axis which becomes a convenient source of entrainment into the inner spiral. However, for large evclones, on the order of several feet in diameter, the change of several inches of liquid is readily handled by a sump a few feet deep. If a stripper exists in place of the sump, this pressure gradient may cause abnormal action on the top stripping tray. This is one reason for introducing a vortex breaker near the top of the sump, to break up the tangential velocity and produce a more uniform pressure over the sump area. Except for a slight increase of turbulence in the cyclone proper, this vortex breaker is not undesirable, since reduction of tangential velocity in the inner cylinder reduces the over-all pressure drop. The tangential velocity in the annular space is probably only very slightly affected. This vortex breaker has a second purpose. If it is allowed to extend along the closure walls, up into the cyclone body proper, it will eliminate swirl of the collected liquid, which can build up an appreciable layer of liquid and thus increase reentrainment.

**Separation in Cyclones.** The basic mechanism of separation in cyclones is shown schematically in Figure 8b. A droplet which is at point P, just after entering the cyclone, falls outward owing to centrifugal force, as it is swept downward by the gas. Since its trajectory is sufficiently steep, the drop

reaches the wall before the gas begins to move inward into the exit cylinder, and separation is accomplished. Another droplet, initially at point P', and possibly somewhat smaller, does not separate but is swept inward by the gas and carried out as entrainment. Thus, whether or not a given particle separates depends on its initial position and its size, which determines its settling velocities. Since particles of a given size will initially be spread across the whole inlet, in general only some of them will separate. This gives rise to the concept of separation efficiency,  $F_D$ , for single-sized drops. A typical curve of separation efficiency vs. drop diameter, for a given combination of cyclone, fluid properties, and flow rate is given in Figure 9. Two regions can be distinguished. For drop diameters larger than a certain "minimum separable drop diameter,"  $D_p$ , separation is complete. As the diameter decreases below Dn, the separation efficiency decreases but remains finite for all finite drop sizes.

To obtain the actual separation efficiency, this figure must be combined with the size-distribution curve for the drops being separated. As discussed below, this may mean the sizes created upstream of the cyclone, or it may mean those created in the cyclone. In any case, a drop-size distribution similar to that of Figure 5 applies. From this figure, or from Equation (1) directly, a size frequency curve, such as given in Figure 10, can be constructed. The over-all efficiency of separation,  $F_s$ , or the fractional entrainment loss,  $1 - F_s$ ,

can then be obtained by averaging:

$$1 - F_{\rm s} = \int_{a}^{1} (1 - F_{\rm B}) d\tau' = \int_{a}^{1} (1 - F_{\rm B}) \left[ \frac{d\tau'}{d(D/D_{\rm m})} \right] d(D/D_{\rm m}). \eqno(9)$$

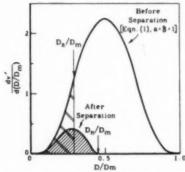


Fig. 10. Typical drop-size distributions before and after separation.

In Figure 10, the lower curve shows values of the product of  $(1-F_B)$  and the size frequency. Thus, the shaded area under this curve represents  $1-F_B$ .

From Figure 10, it is seen that the dependence of the entrainment separation on the minimum separable drop diameter is unknown, unless the complete curve of Figure 9 is known. A more useful critical size, when it can be obtained, is the cut-off diameter,  $D_s$ . This is defined by setting the fraction of all drops smaller than  $D_s$  equal to the over-all fractional entrainment loss,  $1-F_s$ . In Figure 10, it is fixed by making the two shaded areas equal in area.

While typical values of a = 1,  $\delta = 1$ have been used as an example, it is quite likely that other values actually apply. However, for similar processes, where these parameters can be expected to be the same, even if they are unknown, the ratio  $D_s/D_m$ , or even  $D_{\rm m}/D_{\rm m}$ , can serve as a means of comparing efficiency. It must be stressed that use of  $D_s$  or  $D_n$  alone does not provide a satisfactory comparison of liquid separation under different conditions. Because of the value of separation diameters such as these in analyzing solid separation, there is a natural tendency, which must be overcome, to use them alone, for liquid separation.

# Estimation of Separation Diameters.

As a basis for estimating such separation diameters as  $D_s$  and  $D_s$ , the drop trajectories, as sketched in Figure 8b, should be evaluated. As long as the drop diameter is small enough compared to the radius of curvature of its path, the trajectory can be calculated as a simple settling under the influence of centrifugal force. Various authors (18, 25, 27)

have calculated separation ability in this manner. However, in general, their methods are unsatisfactory in one or more of the following respects:

- Stokes' law is assumed in calculating particle trajectories, whereas particle Reynolds numbers for typical conditions may be much greater than unity.
- Trajectories are based upon unrealistic tangential velocities in the unit. For example, in some instances (25, 27), it is assumed that tangential velocity is constant and equal to the inlet velocity.
- Calculations are usually limited to estimation of the minimum separabledrop diameter, Dn, which must be adjusted to estimate separation efficiency.
- The effect of main-stream turbulence on the drop motion is neglected.

It is believed that the first three objections can be adequately met by existing methods of analysis to allow prediction of curves similar to Figure 9, for "direct" separation, i.e., separation when turbulence is not appreciable. A suggested method of handling the turbulence effect is discussed below.

The results of all the theoretical treatments based on direct separation show that the critical value of drop size for separation increases with increase in inlet area, decrease in volumetric flow, and decrease in cyclone height. The refinements suggested above would not affect these conclusions. Small inlet areas, high flows, and tall cyclones therefore are desirable. The benefits of the first two are offset by their attendant increase in pressure drop, and so a balance between separation size and pressure drop dictates the optimum combination. As to the third, any desired degree of separation might be expected to be attained merely by increasing the cyclone height sufficiently. Actually, this method does not seem to work. Increase in height beyond a certain value has very little effect on efficiency. Auother mechanism apparently counteracts the benefit of increased height.

This second mechanism is the effect of turbulence. Very small droplets, instead of settling smoothly as shown in Figure 9, have a general settling motion but are also thrown around violently by the turbulent motion. The picture is similar to any type of turbulent entrainment, such as sediment transport in rivers, sandstorms, and ocean spray. In fact, some idea of the critical size where the effect of turbulence is first felt can be obtained from a concept developed by Kalinske (12) for the first of these examples. By both semitheoretical reasoning and field ex-

periments on sediment transport, he found that particles larger than those whose settling velocities equalled the friction velocity were never entrained from the bed of the river. The friction velocity is defined as:

$$u^* = \sqrt{g_c \tau_o / \rho_g} \qquad (10)$$

where  $\tau_0$  is the shear stress at the boundary. By consideration of turbulent shear stresses,  $n^{\Phi}$  is found to be approximately equal to the velocity fluctuations. Particles whose settling velocities are greater than the turbulent velocity fluctuations apparently settle smoothly, while those whose settling velocities are smaller than these fluctuations are severely hindered in settling.

If we express  $\tau_0$  in terms of a friction factor.

$$f = \tau_o \left/ \left( \frac{\rho_g v_o^2}{2g_c} \right) \right. \tag{11}$$

then Equation (12) becomes

$$u^* = v_n \sqrt{2f} \qquad (12)$$

Thus, if Stokes' law applies to the particle motion, the critical Kalinske diameter is

$$D_k = 3[2f]^{\frac{1}{4}} \left[ \frac{\mu_g r_o}{(\rho_L - \rho_g) v_o} \right]^{\frac{1}{4}}$$
(13)

Although  $D_k$  is a minimum separable particle diameter rather than a cut-off diameter, Equation (13) shows qualitatively the dependence of turbulent entrainment on the independent variables,

The Kalinske diameter can be shown to be about equal to another critical diameter, developed by Sewell (31 and 14), for acoustic theory and applied to turbulent phenomena by Baron (3). This diameter represents the transition between large particles, whose inertia overcomes all effects of the flow fluctuations, and the small particles, whose inertia provides a negligible resistance to the flow fluctuations. This may partially explain Kalinske's success in using his concept for the correlation of sediment transport. It also shows why  $D_k$ is not just a reentrainment parameter but is tied up with the initial separation

#### Drop-size Distribution in Cyclones. As discussed above, these separation

As discussed above, these separation diameters must be combined with the drop-size distributions to obtain actual entrainment efficiencies. Moreover, these distributions, especially the maximum diameters, depend on the same variables as the separation diameters. Thus, between two similar cases, better entrainment separation will not necessarily occur in the one with the lower value of the separation diameters, but will depend on the ratios between these

separation diameters and the maximum drop sizes.

We have already discussed the distribution of sizes for the drops entering the cyclone. In many cases these drops remain intact until striking the wall. In other cases conditions in the cyclone may be severe enough to cause further atomization. This will occur if the maximum stable drop diameter in the cyclone,  $D_e$ , is smaller than the maximum drop diameter entering the cyclone.

The breakup in the cyclone, when it occurs, is terminal velocity breakup, discussed by Hinze (8), among others, and results from the same opposing forces previously discussed for breakup in pipes. However, in this case the inertia effects are created by the high velocities of the drops relative to the continuous phase. As an example, the maximum stable diameter for rain drops is about 7.2 mm. (16). When the effective gravitational force is increased, this maximum stable size is considerably decreased.

Quantitatively, Hinze (8) shows that terminal-velocity breakup corresponds to a critical Weber-number concept. Thus, in the cyclone, the maximum stable drop diameter  $D_e$  can be calculated from:

$$\frac{D_c u_{D_c}^2 \rho_g}{g_c \sigma} = W \varepsilon_c \qquad (14)$$

where  $u_{De}$  is the drop-settling velocity. While Equation (14) probably shows trends reasonably well, use of values of  $We_e$  obtained for freely falling drops breakup in cyclones may introduce an error, since an extrapolation in drop Reynolds number from about 1000 to about 1 to 10 is involved. It is evident that study of breakup in this low-Reynolds-number region requires experiments on drop dispersion in a centrifugal field, i.e., a cyclone. The parameters, a and b, which are also unknown, could be evaluated by the same experiments.

Mass Transfer in Cyclones. The mass transfer or flashing occurring in cyclones may be quite important, especially when the pressure drop in the cyclone transfer line is large. This transfer occurs in three steps:

- 1. During the separation of the drops.
- 2. From the liquid film on the walls.
- 3. From the liquid pool in the sump.

Each of these can be considered separately.

Study of the drop trajectories and pressure profiles as in Figure 8 shows that, in the first step, transfer is occurring substantially at inlet conditions. The gas flowing near the inner cylinder may not contact many drops. However, variations in concentration in the gas are only significant in the unlikely case that the entering liquid and vapor are far from equilibrium. Moreover, the

turbulence in the gas tends to eliminate any concentration gradients. Thus, even if mass-transfer efficiency is high, the first step merely acts to ensure approach to equilibrium at inlet conditions.

This efficiency of transfer in this first step should be quite high since the small drops, with high surface-volume ratios, achieve abnormally high velocities through the gas and are subjected to strong forces to cause internal motion. Combination of separation trajectories with mass-transfer correlations for individual drops should allow an estimation of this efficiency. For the gas-side resistance, correlations such as Frössling's (24) can probably be used. For the liquid-side resistance, a minimum rate can be calculated from the laws of diffusion in a stagnant drop. This should be revised upward to allow for various internal motions, as discussed by Hughes (9) and Hughes and Gilliland (10).

In the second step, mass-transfer efficiency is somewhat lower, since the liquid is quite far removed from the main gas stream. As discussed above, the pressure reduction occurring as the film flows inward along the closure wall results in much less volatilization than that corresponding to equilibrium, since the stripping action of the vapor does not occur. This effect is even more marked in the third step, since the liquid in the sump is practically out of contact with the gas. This poor mass transfer is unfortunate since the liquid is at its lowest pressure in the sump, where pressures often correspond to cyclone-exit

From these considerations, we would expect that the over-all degree of volatilization is somewhat higher than the equilibrium value at the cyclone inlet and considerably lower than that at the cyclone exit. These cyclone-exit conditions have long been termed flash-zone conditions, obviously a misnomer, since entrance conditions are a more reliable indication of the degree of flashing.

# Summary and Recommendations

This general analysis of mechanical entrainment separation in flash vaporization is designed to present more questions than it answers. This type of critical review of the many factors of the problem seems to these writers to be a necessary prerequisite to the study of individual details. The major conclusion is that the entire system must be designed as a unit; it is impossible to design a flasher for a given entrainment separation without knowledge of conditions upstream. Furnace and flasher designs must be tied together to get the proper pressure relations for the desired flash and, at the same time, not to create a dispersion that is too fine to

separate.

From this critical review, a number of recommendations for further study have been obtained. Since the emphasis of the review was on cyclone-type separators, many of these recommendations deal specifically with cyclones:

- For two-phase flow in pipes, bends, valves, expansions, contractions, orifices, etc., pressure drops and dispersion sizes should be determined in the annular- and dispersed-flow regime. Studies should include lengths of flow necessary to establish new dispersion sizes.
- When pilot-plant study of flashing is considered, instrumentation for the furnace and transfer lines should provide for study of flow regimes and their effects on temperature gradients, heat transfer, and temperature sensitivity.
- 3. For all types of separators, test runs should be made to give simultaneously the over-all entrainment: the dispersion sizes at the entrance, inside the unit, and at the exit; and the flow conditions. At times, these measurements may be difficult to obtain, but they are really essential to good design procedures. Such test runs are especially needed for plate scrubbers, since theoretical analyses of plate action has not vet been successful. Similarly, the flow in many impingement separators is too complex for quantitative treatment, and entrainment test runs are necessary.
- For cyclones and centrifugal-flow separators of various kinds, theoretical study, which may minimize the need for the test runs described above, can be considerably furthered by:
  - a. Pressure profiles along surfaces and in the main stream. Special attention should be given to points near the inlet and to the effect of inlet modifications.
  - Velocity profiles and turbulence intensities and scales, especially in the region where separation occurs.

# Notation

- a = dimensionless skewness parameter, Equation (1)
- D = drop diameter, L
- $D_k = \text{Kalinske}$  or turbulent-separation diameter, Equation (13), L
- $D_L$  = transfer-line diameter, L
- $D_{\mathbf{m}} = \text{maximum-drop diameter}, L$
- $D_n^m$  = diameter of smallest drops for which  $F_D = 1$ , L
- $D_a = \text{cut-off diameter to make } 1-F_a$ =  $v'(D_a)$ , L
- $D_t = \text{maximum stable drop diameter}$ in pipe, L
- $F_D$  = separation efficiency for drops

of a single size

 $F_* = \text{over-all separation efficiency}$ 

f = friction factor, Equation (11)(not a true friction factor, since defined only for one velocity component)

 $g_c = \text{conversion}$  factor between force and (mass X acceleration),  $ML/Ft^2$ 

k = absolute wall roughness, L $M_a$  = molecular weight of gas, M/mole

 $p = \text{pressure}, F/L^2$ 

R = universal gas constant, FL/(mole) 7

 $Rc_t = \text{transfer-line Reynolds number,}$ Dipol 1/40

r = radius from cyclone axis, L

 $r_a$  = value of r at inside of cyclone wall. L

T = absolute temperature, T

 $u^* = iriction$  velocity, Equation (10), L/t

V = velocity, L/t

 $V_a = acoustic$  velocity, Equation (5), L/t

 $V_e = \text{critical velocity for two-phase}$ flow, L/t

 $V_a = \text{critical}$  and acoustic velocity for perfect gas, Equation (6), L/t

 $V_{in} = \text{inlet velocity}, L/t$ 

 $V_t = average velocity in transfer$ line, L/t

v = tangential velocity of the gasat a point, L/t

v' = volume fraction of drops with diameters less than D

 $v_0 = \text{extrapolated}$  value of v at  $r = r_o, L/t$ 

 $We_e = critical$  Weber number, Equation (2)

 $We_t = \text{critical Weber number for pipe}$ flow, Equation (3)

x = weight fraction of vapor flowing

 $y = \ln[aD/(D_m - D)]$ 

 $\delta = \text{dimensionless uniformity par-}$ ameter, Equation (1)

 $\kappa = \text{ratio of specific heats, } C_P/C_V$ 

 $\kappa_a = \text{value of } \kappa \text{ for gas}$ 

 $\mu_a = \text{gas viscosity}, M/Lt$  $\mu_L = \text{liquid viscosity}, M/Lt$ 

 $\rho = \text{mixture density}, M/L^3$ 

 $\rho_g = \text{gas density}, M/L^3$ 

 $\rho_L = \text{liquid density, } M/L^3$ 

 $\sigma = \text{surface tension}, F/L$ 

 $\tau_o = \text{shear stress}$  at a boundary,  $F/L^2$ 

Letters in Notation: Capital letters in Notation signify units in a consistent system as follows: M, F, L, and T indicate mass, force, length, and temperature; small t designates time.

## Literature Cited

1. Alexander, L. G., and Coldren, C. L., Ind. Eng. Chem., 43, 1325 (1951).

Allen, W. F., Jr., Trans. Am. Soc. Mech. Engrs., 73, 257 (1951).
 Baron, T., Personal Communication

Baron, T (1950).

4. Bergelin, O. P., and Gazley, Carl, Jr., Paper at Heat Transfer and Fluid Mechanics Institute, Berkeley (June

22-24, 1949) 5. Bergelin, O. P., Kegel, P. K., Carpen-

ter, F. G., and Gazley, Carl, Jr., Paper at Heat Transfer and Fluid Mechanics Institute, Berkeley (June

Mechanics Institute, Berkeley (June 22-24, 1949).

6. Clay, P. H., Nederland, Akad, Wetens, 43, 852, 979 (1940).

7. Courant, R., and Friedrichs, K. O., "Supersonic Flow and Shock Waves," 1st ed., pp. 1-25, Interscience, New York (1948).

8. Hinze, J. O., Applied Scientific Research, A1, 263 (1949-1950).

9. Hughes, R. R., Sc. D. thesis, Massachusett Institute of Technology (1949).

setts Institute of Technology (1949) Hughes, R. R., and Gilliland, E. R. Chem. Eng. Progress, 48, 497 (1952)

 Johnson, H. A., and Abou-Sabe, A. H., Paper No. 51-A-111, Am. Soc. Mech. Engrs. Meeting, Atlantic City (No-

vember, 1951). 12. Kalinske, A. E., Univ. Penn. Bicenten-nial Conf., Univ. Penn. Press, Philadelphia (1941).

13. Kosterin. S. I., Izvest. Abad. Nauk S.S.S.R., No. 12, 1824 (1949). 14. Lamb, H., "Hydrodynamics," 6th ed.,

Cambridge University Press (1932); Ist American edition, p. 657, Dover, New York (1945). ane, W. R., Ind. Eng. Chem., 43, 1312

15. Lanc.

(1951). Lenard, P., Meteor Z., 21, 249 (1904). Lewis, H. C., Edwards, D. G., Goglia, M. J., Rice, R. L., and Smith, L. W.,

M. J., Rice, R. L., and Smith, L. W., Ind. Eng. Chem., 40, 67 (1948).
 Lissman, M. A., Chem. & Met. Eng., 37, No. 10, 630 (October 1930).
 Lockhart, R. W., and Martinelli, R. C., Chem. Eng. Progress, 45, 39 (1949).

Merrington, A. C., and Richardson, E. G., Proc. Phys. Soc. (London), 59, 1 (1947).

21. Mugele, R. A., and Evans, H. D., Ind.

Mugele, R. A., and Evans, H. D., Ind. Eng. Chem., 43, 1317 (June 1951).
 Nukiyama, S., and Tanasawa, Y., Trans. Soc. Mech. Engrs. (Japan), 4, No. 14, 86 (1938); 5, No. 15, 138 (1939); 6, No. 18, 63, No. 22, II-7, No. 23, II-8 (1940).
 Perry, J. H., Ed., "Chemical Engineers' Handbook," 3rd ed., pp. 387-390, McGraw-Hill, New York (1950).

(1950).

24. Ibid., pp. 546-547.

Ibid., pp. 1013-1049.
 Pollak, A., and Work, L. T., Trans.
 Am. Soc. Mech. Engrs., 64, 31

27. Rosin, P., Rammler, E., and Intelmann, E., Z. Ver. deut. Ing., 76, 433 (1932)

Schneider, F. B., Paper No. 49-A-126, Am. Soc. Mech. Engrs. Annual Meeting, New York (November 27,

29. Schneider, F. B., Gen. Elec. Rev., 53,

No. 2, 22 (February, 1950).
30. Schweppe, J. L., and Foust, A. S.,
Paper presented at Am. Inst. Chem. Engrs. Meeting, Atlantic City (De-

cember, 1951).
31. Sewell, C. J. T., Trans. Roy. Soc. (London), 110-A, 239 (1910).
32. Shepherd, C. B., and Lapple, C. E., Ind. Eng. Chem., 31, No. 8, 972 (August, 1939). id.,, 32, No. 9, 1246 (September,

33. Ibid., 3: 1940).

Silcox, H. E., Ph.D. thesis, University of Illinois (1942).
 Stroebe, G. W., Baker, E. M., and Badger, W. L., Trans. Am. Inst. Chem. Engrs., 35, 17 (1939).
 ter Linden, A. J., Engineering, 167, 165 (February 18, 1949).
 Wetzel, R., Ph.D. thesis, University of Wisconsin, (1951).

Wisconsin (1951).

#### Discussion

E. J. Kelly (Carrier Corporation, Syracuse, N. Y.): Did you ever have a careless mechanic who hooked up one of these cyclones just backwards, and put the liquid to be separated into the conventional outlet, taking the vapor from the conventional inlet?

R. R. Hughes: No. This would make the cyclone a knockout box, depending on the turnaround for the separation. This arrangement would work if the tank were large enough. For the flows, we are talking about, with the normal velocity range of 30 to 50 ft./ sec., too much material would be entrained.

J. E. Walkey (California Research Corp., Richmond, Calif.): This is an interesting contribution to a field which has been dealt with largely by analogy with the mass-velocity limitations that are encountered in fractional-distillation columns. It points up the need for more fundamental work in the field. Have you applied the concept presented here, to the analysis of the operation of an actual vacuum flasher and with what degree of success?

R. R. Hughes: The concepts have been applied to quite a few cases, in both trouble-shooting and design. We feel we have been quite successful, although a great deal remains to be done. Where modifications have been made we have been able to show definite improvement. In others any improvement is inside the experimental limits of the test data. Adverse effects have never been observed.

J. E. Walkey: In your consideration of approach to equilibrium in the systems studied, have you been able to differentiate between the lack of attainment of equilibrium due to the limitations of mass-transfer kinetics vs. the apparent lack of attainment of equilibrium due to the entrainment of liquid in overhead vapors?

R. R. Hughes: We haven't evaluated the problem in this way, but it sounds like an interesting suggestion. Normally, we feel that the contaminants due to entrainment are completely nonvolatile. Thus, the entrainment is one problem, while the nonattainment of equilibrium is another one, which results in loss of overhead rather than contamination.

(Presented at A.I.Ch.E. French Lick, Ind., Meeting.)

# STUDIES ON THE MOTION OF GAS BUBBLES IN LIQUIDS

Fred N. Peebles and Harold J. Garber

University of Tennessee, Knoxville, Tennessee

HE role of gas bubbles is an important one in many physical operations and chemical processes involving interaction between liquid and gaseous systems. In some operations the transfer of mass between gas bubbles and the contiguous liquid phase is the very essence of the operation. In others the kinematic behavior of gas bubbles is bound up with secondary aspects of the operation. Examples of the former include rectification, absorption and stripping in bubble-cap and perforated-plate contacting devices and chemical reactions between liquid and gaseous reactants. Boiling is an operation in which the formation and movement of gas bubbles appear as a secondary aspect of the heat-transfer operation.

Investigators concerned with predicting the performance of equipment in those operations and processes involving interaction between gas bubbles and liquids have realized the complexity of the complete problem and have considered in detail the component mechanisms that make up the operation (7). The motion of gas bubbles in liquids is such a component mechanism common to the examples cited and many others. It is the purpose of this paper to describe an initial phase of an extensive investigation on gas-bubble behavior.

The scope of the over-all investigation includes studies on the motion of both single gas bubbles and gas-bubble streams in liquids. One of the objectives is to discover by experimental and theoretical analysis means for predicting the velocity and drag characteristics of moving gas bubbles in terms of the physical properties of the liquids and the gas-bubble size. The material presented in this first report is limited to the motion of single gas bubbles in liquids.

# Summary of Previous Work

The prediction of the velocity of a gas bubble in a liquid is a hydrodynamical problem and falls within the more general problem of the flow of fluids The motion of gas bubbles is an important factor in mass- and heat-transfer operations involving the contacting of liquids and gas bubbles. The present paper describes work on the flow characteristics of single gas bubbles in liquids with particular emphasis on the steady-state velocity and the drag coefficient.

Experimental work consisted of determination of the steady-state velocity of air bubbles in twenty-two liquids. The choice of the liquids was such that the effect of variation in liquid density, viscosity, and surface tension on the gas motion was evident. The effect of gas-bubble size was shown by the use of gas bubbles of 0.002 to 0.025 ft. equivalent spherical radius.

Four distinct types of bubble motion in liquids were noted, two corresponding to the viscous and transition regions and two to the turbulent region. Two types of motion within the turbulent region result from the variation of gas-bubble deformation. Quantitative relations for the steady-state velocity and drag coefficients in terms of liquid properties and gas-bubble size were developed for the four types of motion.

In the viscous and transition regions, the Reynolds number was found to be the important independent variable in analyzing the experimental data. For the other two regions where the gas-bubble deformation was significant, combinations of the Weber and Froude numbers into new dimensionless parameters were used to describe the data. The limits of each of the four regions of bubble behavior were also determined as functions of the dimensionless groups cited.

past bodies in the fluid stream, a question that has interested investigators in that field since the time of Newton. Earlier speculations (9, 11, 14, 19) were concerned with the ideal fluid hypothesis, which used as its basis a fluid having zero viscosity. The conclusions from these speculations are of little direct benefit to the defined problem since for steady flow the ideal fluid offers no resistance to flow past a body immersed in the fluid stream. This is contrary to experience with all real fluids.

Stokes (24) contributed to the knowledge on the general problem of fluid flow past bodies in the stream by solving the equation of viscous motion for the case of a rigid spherical particle immersed in a fluid of infinite extent. The main result of this analysis, an expression for the terminal or steady-state velocity of a particle, is known as Stokes' law. When applied to rise of a gas bubble in a liquid, Stokes' law gives

$$U_{x} = \frac{2g(\rho_{1} - \rho_{2})R_{h}^{2}}{9\mu} \tag{1}$$

where

 $U_x=$  steady-state, terminal rising velocity, ft./ sec.

g = gravitational acceleration, 32.17 ft./

 $ho_1=$  liquid density, lb. mass/cu.ft.

 $ho_2=\,$  gas density, lb. mass/cu.ft.

 $R_b = \text{equivalent spherical gas-bubble radius,}$ 

 $\mu = \text{liquid viscosity, fb. mass/(ft.)(sec.)}$ 

Agreement of Equation (1) with experiment depends on the degree to which the assumptions underlying Stokes' law can be satisfied, i.e., spherical rigid particle with no slip at the particle boundary, inertia forces small in magnitude compared to viscous forces, gravity the only extraneous force, and constant fluid properties.

The inability to solve the hydrody-

namic equations of motion for systems where Stokes' law does not apply has led to the practice of employing an arbitrarily defined drag coefficient to summarize experimental data. The drag coefficient is usually defined by the equa-

$$D = \frac{C_D \rho_1 U^2 A}{2g_c} \tag{2}$$

[] = total fluid resisting force, lb. force  $C_D = ext{drag coefficient, dimensionless}$ 

A = cross-sectional area of particle perpendicular to the direction of flow, sq.ft.

U = particle velocity, relative to fluid, ft./sec.  $g_c =$  gravitational conversion factor between force and mass, 32.17 (lb. mass)(ft.)/ (sec.)2(lb. force)

The drag coefficient is somewhat analogous to the Fanning friction factor but more complex since it contains the effect of both skin drag and form drag.

Allen (2) and Robinson (21) performed experiments to show the applicability of Stokes' law for gas bubbles rising in liquids. Allen studied the motion of air bubbles ( $R_b < 0.001$  ft.) in water and in aniline and the data indicated excellent agreement with Stokes' law for Re < 2 where

$$\mathrm{Re} = \mathrm{Reynolds\ number}, \frac{2R_LU\rho_1}{\mu}, \ \mathrm{dimensionless}$$

For Re > 2 the departure from Stokes' law was found to be significant. Further, for  $Re \leq 200$  the drag coefficient agreed with that of solid spheres moving in liquids. Allen's experimental results could be expressed in terms of the drag coefficient by the relations

$$C_D = 24 Re^{-1}, Re \le 2$$
 (3)

$$C_D = 18.5 \ Re^{-0.6}, \ 2 \leqslant Re \leqslant 200$$
 (4)

Robinson's data using lubricating oils confirmed these results.

Miyagi (16) studied the rate of rise of single air bubbles in water over a size range of  $0.003 < R_b < 0.013$  ft. Data on terminal gas-bubble velocity as a function of gas-bubble size indicated a maximum velocity at an Rb of approximately 0.005 ft., followed by a decreasing velocity up to  $R_b = 0.010$  ft. For still larger size bubbles the terminal velocity seemed to be independent of size.

Bryn (3) classified the motion of air bubbles through aqueous solutions of alcohol and glycerine over a wide range of sizes into three distinct types:

1. Small bubbles, approximately spherical, rising in straight lines for water at room temperature, Rs < 0.005 ft.

2. Medium-sized bubbles, flattened horizontally, rising with rocking, pendulumlike, oscillating or spiral movements for water at room temperature, 0.005 < R<sub>b</sub> < 0.013 ft.

3. Large bubbles greatly deformed, assuming a

mushroomlike shape, rising relatively straight, very unstable, tending to break easily into numerous smaller bubbles for water at room temperature, R<sub>h</sub> > 0.013 ft. Bryn confirmed the definite maxima reported by Miyagi in the velocity-radius curve and was able to express the relation between velocity and bubble radius quantitatively for the large-bubble region by

(2) 
$$U = \beta \sqrt{a} + \delta \frac{R_b}{\sqrt{a}}$$
 (5)

 $\beta = \text{orbitrary constant}$ 

 $\delta = arbitrary constant$ 

y = liquid surface tension, lb. force/ft.

$$\gamma = \text{liquid surface tension, lb. force/ft.}$$

$$a = \left[\frac{2\gamma g_c}{g\rho_1}\right]^{1/2} \text{Laplace's capillarity constant,}$$
ft.

O'Brien and Gosline (18) surveyed the literature on the velocity of gas bubbles and conducted experiments in which the rise of air bubbles through water, mineral oil, and livestock oil were studied in 1.18-, 2.24- and 6-in. glass tubes. Failing in an attempt to deal with the problem from a mechanistic standpoint, O'Brien and Gosline made a dimensional analysis of the variables that could affect the drag coefficient. They found that the drag coefficient should be some function of the Reynolds number. the Weber number  $(2R_b\rho_1U^2/\gamma g_c)$ , the ratio of bubble radius to tube radius, and possibly other dimensionless groups. Having done this, they abandoned this dimensional analysis and did not determine the functional relationships between the dimensionless groups mentioned. Instead, their results for all experiments were plotted as curves showing the variation of the drag coefficient with Reynolds number. Their results indicate that for all three liquids the relation between CD and Re for solids is valid for gas bubbles up to some critical value of the bubble radius peculiar to the particular liquid. Above this critical bubble radius the drag coefficients are much larger than those for solid spheres at the same Reynolds number and the CD vs. Re curve appears to be specific rather than general, depending on the particular liquid involved. Classifications of three types of bubble movement were described quite similar to those of Bryn. Limited experiments were also conducted on the mean velocity of a stream of gas bubbles. In these experiments no measurements of gas-bubble size were made, and no general relations to describe the data were presented.

Kaissling (10) made a dimensional study of the factors affecting the velocity of steam bubbles in vertical boiler tubes. It was claimed that the following dimensionless-group functional relationship should apply

$$\frac{U_x \mu}{\gamma g_c} = f \left[ \frac{\mu^4 g}{\rho_1 g_c^3 \gamma^3}, \frac{\rho_1 R_b{}^2 g}{\gamma g_c} \right] \tag{6}$$

where

f = an arbitrary function

Attempts to determine the functional relation involved were made without success from data given by Schmidt

Wigner (28) made some speculations regarding the velocity of gas bubbles in liquids based on a dimensional analysis of the variables: bubble velocity, liquid density, liquid viscosity, and liquid-surface tension. It was intended that such an analysis should give an expression for the terminal velocity of a bubble that was growing by transfer of material into it; hence the bubble radius was not considered in the analysis. Such an analysis led to

$$\frac{U_x \mu}{\gamma g_c} = f_1 \left[ \frac{\rho_1 \gamma^3 g_c^3}{\mu^1 g} \right] \tag{7}$$

f. = arbitrary function

From some observations with water by Cooper (1) the arbitrary function was evaluated and was expressed by

$$f_1 = 2 \left[ \frac{\rho_1 \gamma^3 g_c^3}{\mu^4 g} \right]^{-1_k} \tag{8}$$

Substituting f1 from Equation (8) into Equation (7) gives

$$U_x = 2 \left[ \frac{\gamma g g_c}{\rho_1} \right]^{1/4} \qquad (9)$$

No attempt was made to verify this deduction experimentally for other liquids, nor was an explanation of the mechanism that brings about this result put forth.

Levich (13) considered the boundarylayer theory with reference to liquid-gas interfaces and applied it to the computation of the total resisting force that acts upon a gas bubble rising in a liquid. The analysis of the boundary-laver behavior applied to a spherical gas bubble led to the following expression for the terminal bubble velocity,

$$U_{x} = \frac{R_{b}^{2}g(\rho_{1} - \rho_{2})}{9\mu}.$$
 (10)

This result was claimed to be valid over the range 1 < Re < 1500. However, it was pointed out that experimental verification of Equation (10) would be difficult because of bubble deformation,

Gorodetskaya (8) conducted experiments on the rate of rise of single air bubbles in water and a number of normal alcohols with the express purpose of attempting verification of the conclusions of Levich. In the main the experimental bubble velocities were approximately 30% lower than those predicted by Equation (10), but were somewhat higher than bubble velocities measured by other investigators under corresponding conditions. Gorodetskaya argued that these discrepancies exist because the bubble velocities are very sensitive to the presence of the slightest trace of impurities in the liquids used and that all the liquids he used in the work were carefully purified, whereas previous investigators had ignored this precaution. Data were presented to show that concentrations of surface-active substances as low as 10-6 molar are sufficient to affect the velocity of bubbles in liquids, these effects being attributed to changes in surface viscosity.

Datta, Napier and Newitt (5) made measurements of the velocity of single air bubbles in water. Their data agree with those of Allen and Miyagi under corresponding conditions. In the range of gas-bubble sizes described by Bryn as large bubbles ( $R_b > 0.013$  ft.), the velocity was almost independent of size.

Verschoor (26) studied the motion of a stream of air bubbles rising in a column of liquid. Measurements of bubble velocity were made for different rates of air passing through the column without measuring the bubble size. Attempts were made to correlate the data with the dimensionless groups suggested by Kaissling. No general relationships were presented.

Van Krevelen and Hoftijzer (25) made measurements of the velocity of a stream of air bubbles rising in water, cyclohexane, mineral oil and solutions of glycerine and saponine. When the results were expressed in terms of the drag coefficient and Reynolds number, deviations from the data for solid spheres were obtained similar to the results of O'Brien and Gosline. No general relationships in terms of the physical properties of the system were given.

Davies and Taylor (6) made measurements of shape and rate of rise of air bubbles in water and nitrobenzene. The size of bubbles studied covered the range  $0.023 < R_b < 0.120$  ft. Photographic methods were used to measure the actual bubble shape, and it was found that the bubbles had a mushroom-like shape with a spherical cap. For the two liquids used, the steady-state rising velocity seemed to be independent of liquid properties and was related to the radius of curvature of the spherical cap by the relation

$$U_{\infty} = 0.667(gR)^{\frac{1}{6}} \tag{11}$$

where

R = radius of curvature of the spherical cap on a mushroomlike gas bubble, ft.

Further, their data indicated a direct proportionality between the radius of curvature of the spherical cap and the equivalent spherical radius based on the gas-bubble volume

$$R = 2.3R_h \tag{12}$$

Rosenberg (22) performed extensive experiments on the velocity and shape of air bubbles in water. Results when plotted as the drag coefficient vs. the Reynolds number exhibited the characteristics of the previous investigators cited, i.e., agreement with the data for solid spheres for low values of the Reynolds number with significant deviation from the solid-sphere relation above some critical value. It was postulated that this critical value is related to a dimensionless parameter.

$$\frac{\mu^4 g}{\rho_1 g_c^3 \gamma^3} .$$

Since experiments were performed with water only, the quantitative effect of this parameter was not determined. Measurements of the bubble shapes indicated four general categories, dependent upon the magnitude of the prevailing Reynolds number:

a. Spherical bubbles, Re < 400

b. Oblate spheroids of varying geometric proportion, 400 < Re < 1100

c. Oblate spheroids of constant geometric proportions, 1100 < Re < 5000

d. Mushoom shape with spherical cap, Re > 5000

For the range, 5000 < Re < 40,000, the data agreed with results of Davies and Taylor, as expressed by Equations (11) and (12), within 5%.

General trends of all the experimental data cited are shown in Figure 1 as a plot of the drag coefficient vs. the Reynolds number. The drag characteristics of solid spheres are included on this plot for comparison.

# **Experimental Investigation**

The review of previous work on the motion of gas bubbles indicated that the gas-bubble size and liquid properties, density, viscosity, and surface tension, definitely affect the resulting motion. Exactly how these variables are related to the bubble velocity and the bubble drag coefficients is not clearly shown. Further, the functional relation between various suggested dimensionless parameters containing these variables is not known.

In order to remove these shortcomings, it appeared desirable to perform experiments measuring the steady-state gas-bubble velocity as a function of gas-bubble size using a number of liquids giving a wide variation of the physical propertes cited.

The liquids selected were water, isopropyl alcohol, ethyl ether, pyridine, nitrobenzene, aniline, ocetone, n-butanol, methanol, benzene, toluene, seven solutions of ethyl acetate and cottanseed oil of selected compositions, and four solutions of glacial acetic acid and water of selected compositions. Solutions of ethyl acetate and cottonseed oil were chosen because a wide variation in viscosity (0.4 to 65 centipoise) can be obtained by varying the liquid composition. The aqueous solutions of glacial acetic acid were convenient to obtain a variation in surface tension (72 to 26 dynes/cm.) by changing the liquid composition. The other pure liquids were chosen to extend or complete the range of the physical properties. Air was used as the gas for all experiments.

Physical properties of the liquid system ethyl acetate-cottonseed oil were measured as a function of composition and temperature as another phase of the over-all investigation on gas-bubble behavior (15, 27). For the other liquids used the physical properties were taken from the literature.

Experimental tests were made using a 1.03-in.

I.D. glass tube filled with the desired test liquid.

The tube was 6 ft. long with two measuring intervals, 2 and 3 ft. marked on the tube. The

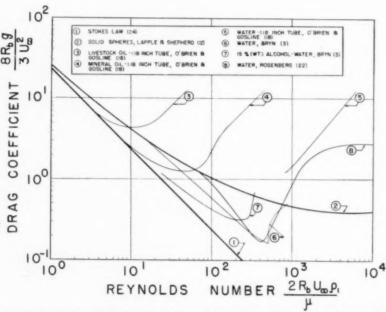


Fig. 1. Results from literature giving drag coefficients of gas bubbles as a function of Reynolds number.

lower measuring interval started approximately 6 in. from the bottom of the tube.

Small-sized gas bubbles were generated at the tip of a glass tube inserted through a rubber stopper in the bottom of the measuring tube. Air was supplied to the bubble-generating tube through connecting glass tubing from a precision gas burette. The gas-measuring burette and a compensating tube were enclosed in a water jacket to minimize error due to temperature changes. A mercury leveling bulb was used to displace air from the burette to the bubble-generating tube. Air flow from the gas-measuring burette to the bubble-generating tube was

regulated by a glass stopcock and a pinch clamp in series. A schematic diagram of the apparatus is shown in Figure 2.

Generation of large bubbles ( $R_b > 0.01$  ft.) by formation at the tips of glass tubes was unsatisfactory in that uniform-sized bubbles could not be formed. This difficulty was circumvented by using a %-in. hemispherical inverted cup for the bubble-generation device. The cup could be filled with a measured volume of air from the gas-measuring burette and then rotated by a turning handle which was operated externally through a stuffing-box arrangement. Careful rotation of the cup released the previously measurements.

ured volume of air as a single bubble into the measuring tube about one time out of three.

The gas burette used was a Hempel compensating type frequently used in precision gas analysis, with a total valume of 100 ml. Graduations on the lowest three ml. were such that the displaced-gas valume could be read directly to 0.01 ml. and estimated to 0.001 ml.

The test procedure using the tip of a glass tube to form gas bubbles was as follows: With the measuring tube filled with a given test liquid, the gas-delivery tube from the burette to the measuring tube was flushed free of liquid by displacing a small volume of air from the burette to the measuring tube. Then with the gas-regulating cocks closed, the gas burette was refilled with air, and the total volume of air contained in the burette was measured. After raising the mercury leveling bulb to give an adequate pressure at the regulating cocks, the cocks were opened carefully to release air bubbles at approximately 10 to 15-sec. intervals. With bubbles generated at these slow rates, simultaneously the bubbles could be counted accurately and the time required for bubbles to rise through the measured intervals could be measured with a stop watch. After approximately 50 bubbles had been released, the flowregulating cocks were closed and the volume of air contained in the burette was measured again. From the volume of air displaced and the number of bubbles generated, the equivalent spherical radius for a bubble was computed. This procedure was repeated at least two other times in order to have triplicate determination of the bubble size. The equivalent spherical radius was taken as the arithmetic mean of these three results. Throughout these three determinations, the time required for a bubble to rise through the measured intervals of liquid was determined from 5 to 10 times. The bubble velocity was taken as the interval length divided b. the arithmetic mean of the rising times.

It was found that using glass bubble-generating tubes in the size range 0.25 to 4-mm. I.D. would produce gas bubbles of a constant size, characteristic of the liquid and the generating tube. Hence the gas-bubble size was varied in the tests by using a number of different sizes of bubble-generating tubes.

For air bubbles with  $R_b > 0.01$  ft, the test procedure was modified to use the bubble-generating cup instead of forming bubbles at the end of a glass tube. The test procedure was different in that a definite valume of air was transferred from the burette to the inverted hemispherical cup. Then the cup was rotated to discharge a single air bubble in the liquid. As the success of this series of operations seemed to be a motter of chance, the procedure was repeated until the desired single bubble was produced. Once a single gas bubble was produced, the time required for a bubble to rise through a measured interval of liquid was determined as described before.

By either of the two test procedures it was estimated that the volume of single air bubbles was in error by no more than  $\pm 5\%$ , corresponding to an error in the equivalent spherical gabubble radius of not more than  $\pm 1.7\%$ . The method used for determining bubble velocities involves at most an error of  $\pm 4\%$  for the highest velocities, giving greater precision for the slower moving bubbles.

# Results of this Investigation

Typical results of the terminal bubble

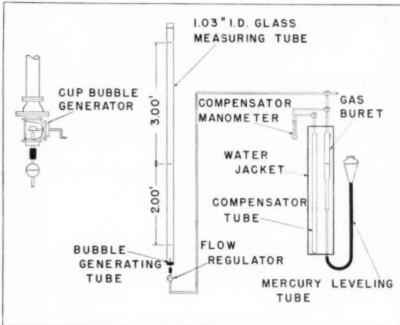


Fig. 2. Schematic diagram of experimental apparatus.

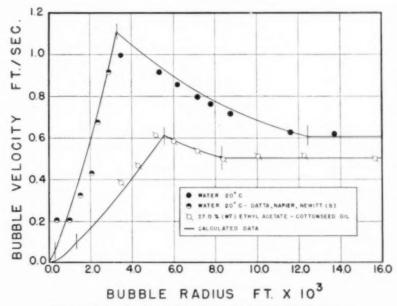


Fig. 3. Typical results of gas-bubble velocity as a function of bubble radius.

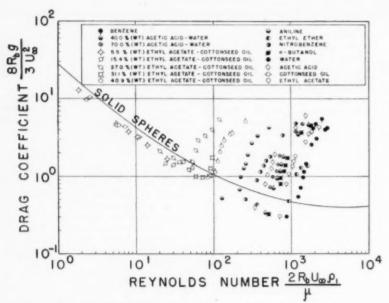


Fig. 4. Results of drag coefficient for gas bubbles as a function of Reynolds number.

velocity as a function of bubble size are shown in Figure 3 for two liquids, water and 27% (by weight) ethyl acetate in cottonseed oil. Some data on water as reported by Datta, Napier and Newitt (5) are included to show the behavior of very small air bubbles in water, since experimental measurements with such small bubbles were not made as part of this investigation. Data for some of the other liquids studied are shown in Figure 4 as a plot of the drag coefficient vs. the Reynolds number. A complete summary of the experimental data is given in Table 1.

In general, the results seem to confirm those of previous investigators. Further, qualitative classifications of the bubble behavior for a particular liquid similar to those of Bryn, O'Brien and Gosline, and Rosenberg were noted, i.e.,

 Re < approximately 2, spherical bubbles moving in rectilinear paths, drag coefficients agree with the result predicted by Stokes' law.
 Re > approximately 2 up to some critical value peculiar to the liquid, spherical bubbles

# TABLE 1 .- SUMMARY OF EXPERIMENTAL DATA

Test Liquid: Water
Surface Tension—71.2 dynes/cm
Density—62.3 pounds mass/cu ft
Viscosity—0.748 centipoise

Rb	Ux	Cp	Re
Ft x 103	Ft/sec		
3.46	1.00	0.30	855
5.32	0.918	0.54	1208
6.19	0.858	0.72	1317
7.15	0.800	0.96	1420
7.74	0.766	1.13	1470
8.72	0.719	1.45	1560
11.6	0.630	2.51	1810
13.7	0.621	3.04	2110
17.8	0.617	4.00	27:10
18.9	0.625	4.18	2920

Test Liquid: 40.0 per cent (wt.) Acetic Acid—Water Surface Tension—40.7 dynes/cm Density—65.3 pounds mass/cu ft Viscosity—1.04 centipoise

Ra	U∞	Co	Re
Ft x 103	Ft/sec		
2.84	0.862	0.33	453
4.37	0.735	0.69	594
5.09	0.695	0.91	654
5.87	0.658	1.16	715
6.36	0.625	1.40	736
7.17	0.595	1.73	789
12.00	0.545	3.45	1206
16.2	0.549	4.60	1650

Density-4	5.1 pounds mass/cu ft 0.233 centipoise		
Rb	U∞	CD	Re
Ft x 103	Ft/sec		
2.35	0.658	0.47	922
3.61	0.543	1.05	1172
4.21	0.532	1.27	1337
4.85	0.555	1.35	1612

Test Liquid: 15.4 per cent (wt.) Ethyl Acetate—Cottonseed Oil Surface Tension—29.9 dynes/cm Density—56.1 pounds mass/cu ft Viscosity—15.0 centipoise

Rь	Ux	CD	Re
Ft x 103	Ft/sec		
4.26	0.508	1.42	24.0
4.97	0.557	1.38	30.7
5.73	0.575	1.49	36.6
6.21	0.598	1.49	41.2

Test Liquid: 27.0 per cent Ethyl Acetate—Cottonseed Oil Surface Tension—29.0 dynes/cm Density—56.2 pounds mass/cu ft Viscosity—11.0 centipoise

Ris	Uz	Cp	Re
Ft x 103	Ft/sec		
3.50	0.383	2.05	20.3
4.30	0.466	1.69	30.4
5.15	0.615	1.17	48.0
6.02	0.586	1.50	53.5
7.15	0.540	2.10	58.6
8.36	0.500	2.87	63.5
10.1	0.513	3.27	78.0
12.3	0.518	3.92	96.2
15.7	0.503	5.30	119.0

Test Liquid: 40.9 per cent (wt.) Ethyl Acetate—Cottonseed Oil Surface Tension—27.3 dynes/cm Density—55.7 pounds mass/cu ft Viscosity—5.00 centipoise

Rb	U <sub>∞</sub>	CD	Re
F+ x 103	Ft/sec		
3.35	0.476	1.27	53
4.15	0.612	0.95	84
5.07	0.622	1.12	105
5.95	0.573	1.55	113
6.83	0.535	2.04	121
7.52	0.510	2.47	127
8.28	0.506	2.77	139
9.88	0.495	3.44	162
10.4	0.501	3.54	171
15.3	0.507	5.10	256

Test Liquid: Ethyl Ether

Surface Tension-15.9 dynes/cm

moving in rectilinear paths, with drag coefficients slightly less than those of an equal-volume solid sphere.

 Re range peculiar to the liquid, deformed bubbles ellipsoidal in cross section, flattened in the horizontal dimension, moving in spiraling,

zig-zag paths, with drag coefficients increasing sharply with Reynolds number.

 Greatly deformed bubbles assuming an irregular mushroomlike shape, rising in a nearly rectilinear path, drag coefficient continues to increase with Reynolds number, but not so sharp

as for Region 3.

In an attempt to analyze the data for all liquids studied, each of the four described regions of bubble behavior was considered separately. Further, it ap-

# TABLE 1.-(Continued)

Test Liquid: Aniline
Surface Tension-41.7 dynes/cm
Density-63.7 pounds mass/cu ft
Viscosity—2.93 centipoise

Rb	Uxx	Cp	Re
F+ x 10 <sup>3</sup> 2.88 4.44 5.17 5.96 6.46 7.27 8.92 10.7 14.6	Ft/sec	0.51	129
	0.695	0.66	216
	0.757	0.97	225
	0.675	1.24	246
	0.641	1.41	260
	0.625	1.87	273
	0.581	2.62	310
	0.540	3.27	366
	0.530	4.20	513

Test Liquid: 10.0 per cent (wt.) Acetic Acid—Water Surface Tension—54.6 dynes/cm Density—64.8 pounds mass/cu ft Viscosity—1.04 centipoise

Viscosity—	1.04 centipoise		
Rb	U <sub>∞</sub>	CD	Re
Ft x 103	Ft/sec		
3.13	0.862	0.36	499
4.82	0.695	0.86	619
5.61	0.685	1.02	710
6.47	0.658	1.28	788
7.02	0.676	1.31	878
7.90	0.658	1.56	963
9.00	0.611	2.07	1017
12.5	0.585	3.13	1353
15.9	0.590	3.90	1739

Test Liquid: Cottonseed Oil Surface Tension—35.5 dynes/cm Density—56.8 pounds mass/cu ft Viscosity—59.0 centipoise

Rb	U∞	Cp	Re
Ft x 103	Ft/sec		-
2.78	0.084	33.70	0.69
4.13	0.192	9.50	2.31
4.91	0.204	10.04	2.60
5.71	0.331	4.48	5.73
6.19	0.342	4.54	6.05
7.15	0.380	4.25	7.30
8.15	0.472	3.14	10.48

Test Liquid: 31.1 per cent (wt.) Ethyl Acetate—Cottonseed Surface Tension—29.9 dynes/cm	Oil
Density—56.0 pounds mess/cu ft Viscosity—7.0 centipoise	

	o centipoise		
Rb	U∞	Cp	Re
Ff x 103 4.14 4.82 5.56 6.03 6.79	Ft/sec 0.605 0.661 0.694 0.641 0.597	0.97 0.95 1.00 1.26	59.5 72.2 91.5 91.7 96.2

Test Liquid: Acetone
Surface Tension—23.7 dynes/cm
Density—49.3 pounds mass/cu ft
Viscosity—0.331 centipoise

Test Liquid:	n-Butanol
Surface T	ension-24.6 dynes/cm
Density-	50.4 pounds mass/cu ft
Viscosity-	-2.948 centipoise
n.	

Rb	U∞	CD	Re	Rb	U <sub>∞</sub>	CD	Re
Fix 10 <sup>3</sup> 12.6 14.9	Ft/sec 0.528 0.507	3.87 4.95	2950 4230	Ft x 103 10.2 14.8	Ft/sec 0.520 0.508	3.23 4.90	333 472

Test Liquid: Methanol
Surface Tension—22.6 dynes/cm
Density—49.3 pounds mass/cu ft
Viscosity—0.593 centipoise

Test	Liquid: Benzene
Su	rface Tension-28.8 dynes/cm
De	insity-54.7 pounds mass/cu ff
Vi	scosity-0.647 centipoise

Rb	U∞	Co	Re	Rb	U∞	CD	Re
Ff x 103 10.1 11.8 14.6	0.500 0.507 0.502	3.46 3.92 4.95	1580 1876 2290	Ft x 10 <sup>3</sup> 12.9 14.2 17.5	Ft/sec 0.515 0.508 0.520	4.15 4.70 5.53	1894 2070 2510

Test Liquid: 5.48 per cent (wt.) Ethyl Surface Tension—34.1 dynes/cm Density—56.5 pounds mass/cu ft	Acetate—Cottonseed	Oil
Viscosity—31.0 centipoise		

Test Liquid: Toluene
Surface Tension—28.4 dynes/cm
Density-54.0 pounds mass/cu ft
Viscosity-0.590 centipoise

			July Campoise				
Rb	U∞	Cp	Re	Rb	Uz	Cp	Re
Ff x 103	Ft/sec				- 23	CD	Re
2.60 3.85 4.61 5.35 4.80 7.52	0.133 0.269 0.329 0.381 0.453 0.625	12.60 4.57 3.65 3.16 2.43 1.65	1.87 5.60 8.08 11.0 14.2 25.4	F+ x 10 <sup>3</sup> 3.27 6.84 8.52 11.0 14.3	Ft/sec 0.805 0.570 0.515 0.510 0.520	0.44 1.80 2.75 3.61 4.53	715 1060 1196 1524 2030

# TABLE 1.-(Continued)

Test Liquid: Ethyl Acetate Surface Tension-22.6 dynes/cm Density-55.8 pounds mass/cu ft Viscosity-0.47 centipoise

Test Liquid: 70.0 per cent (wt) Acetic Acid—Water Surface Tension—34.3 dynes/cm Density—65.3 pounds mass/cu ft Viscosity-1.04 centipoise

Rb	U <sub>∞</sub>	Cp	Re	Rb	Ux	Cp	Re
W D	900	CD	Ke	M.D	0 30	-0	***
$\mathrm{Ft} \times 10^{\circ}$	F1/sec			$Ft  imes 10^{\circ}$	Ft/sec		
2.44	0.833	0.30	710	2.68	0.729	0.43	360
3.78	0.641	0.79	848	4.12	0.704	0.71	536
4.41	0.595	1.07	917	4.80	0.651	0.97	579
5.08	0.575	1.32	1020	5.54	0.636	1.17	652
5.51	0.556	1.53	1071	6.01	0.604	1.41	670
6.21	0.532	1.88	1157	6.77	0.566	1.81	705
8.43	0.516	2.71	1523	11.8	0.522	3.71	1140
9.65	0.485	3.51	1635	14.5	0.515	4.68	1380
10.5	0.492	3.72	1817				
12.9	0.506	4.28	2280				

Test Liquid: Nitrobenzene Surface Tension-42.5 dynes/cm Density-74.7 pounds mass/cu ft Viscosity-1.67 centipoise

Test Liquid: Isopropyl Alcohol Surface Tension-20.7 dynes/cm. Density-49.5 pounds mass/cu ft Viscosity-1.78 centipoise

Rb	U∞	Cp	Re	Rb	U∞	Co	Re
$\rm Ft \times 10^{n}$	F1/sec			$\mathrm{Ft} \times 10^{\circ}$	Ft/sec		
2.75	0.695	0.49	254	2.49	0.625	0.55	127
4.23	0.641	0.88	360	3.82	0.695	0.68	218
4.92	0.610	1.13	399	4.45	0.625	0.98	227
5.68	0.595	1.37	444	5.14	0.610	1.18	256
6.15	0.582	1.56	477	5.57	0.581	1.45	265
6.93	0.582	1.76	536	6.27	0.543	1.82	299
10.9	0.528	3.35	766	12.7	0.490	4.54	510
15.7	0.540	4.62	1130	17.6	0.475	6.68	685

Test Liquid: Pyridine Surface Tension-36.6 dynes/cm Density-61.6 pounds mass/cu ft Viscosity-0.85 centipoise

Test Liquid: Acetic Acid Surface Tension-26.6 dynes/cm Density-65.3 pounds mass/cu ft Viscosity-1.04 centipoise

Rb	U∞	Cp
Ft $ imes$ $10^{\circ}$	Ft/sec	
2.79	0.862	0.32
4.29	0.685	0.79
5.00	0.675	0.94
5.77	0.650	1.17
6.25	0.595	1.37
7.04	0.625	1.70
11.9	0.532	3.60
15.3	0.541	4.48

Re	Rb	U∞	CD	Re
	$Ft \times 10^3$	F1/sec		
514	2.46	0.740	0.39	337
629	3.79	0.646	0.78	453
722	4.41	0.608	1.02	497
803	5.09	0.588	1.26	554
837	5.52	0.564	1.49	576
897	6.22	0.531	1.90	611
1352	12.6	0.480	4.68	1118
1770	16.8	0.489	6.02	1520

peared that a complete theoretical solution of the hydrodynamic description of the flow around the deformed bubble was not likely and that the use of empirical methods and dimensional analysis would be more profitable.

Region 1. Data of Allen (2) using water and aniline, of Robinson (21) using lubricating oils, and from the present investigation using pure cottonseed oil indicate agreement with Stokes' law for the range Re < 2. Thus the equations for the steady-state rising velocity and drag coefficients for bubbles within this region are given by

$$U_{\infty} = \frac{2R_b{}^2(\rho_1 - \rho_2)g}{9\mu} \qquad \text{(13)}$$
 
$$C_D = 24 \; Re^{-1} \; \text{for} \; Re \leqslant 2 \qquad \text{(14)}$$

$$C_D = 24 \ Re^{-1} \text{ for } Re \le 2$$
 (14)

Region 2. The range for this region of bubble behavior for a particular liquid is defined arbitrarily as Re = 2 up to

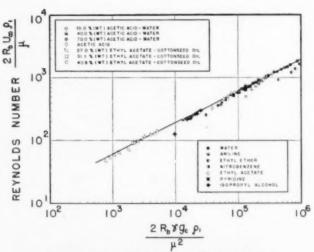


Fig. 5. Correlation of bubble velocity data for region 3.

that value of Reynolds number where the drag coefficient begins to increase abruptly for higher Reynolds numbers. As shown in Figure 4, all the liquids studied except pure cottonseed oil exhibited this phenomenon. Since the Reynolds modulus was general in the description of the drag characteristics of the gas bubbles in this region, it seemed reasonable to use a modification of Equation (14) to correlate the results. Such a procedure had been used by Lapple and Shepherd (12) to fit data on the drag coefficients of solid spheres outside the Stokes' law range.

Treating the data of Allen, Datta, et al., and of this present investigation results in the following equation:

$$C_D = 18.7 \ Re^{-0.68}, Re \ge 2$$
 (15)

The upper limit of the range of applications of Equation (15) cannot be specified until the data of Region 3 are treated.

A relation for the steady-state rising velocity for bubbles in this region can be determined by using the definition for the drag coefficient as given by Equation (2) and solving for the steady-state velocity from Equation (15). Thus for this region, the drag force acting on the equivalent spherical bubble of radius,  $R_b$ , is just balanced by the buoyant force acting upward on the bubble, and the force balance gives

$$\frac{4\pi R_b{}^3(\rho_1-\rho_2)g}{3g_c} = \frac{C_D\rho_1 U_{x}{}^2 \cdot \pi R_b{}^2}{2g_c} \tag{16}$$

Solution for  $C_D$ , neglecting the density of the gaseous phase compared to the liquid density, gives

$$C_D = \frac{8R_b g}{3U_a^2}$$
 (17)

Substitution of Equation (17) in Equation (15) and solving for the steadystate velocity gives

$$U_x = 0.33 g^{0.76} \bigg[ \frac{\rho_1}{\mu} \bigg]^{0.52} \, R_b^{1.28} \qquad (18$$

Region 3. The procedure used for Region 2 could be applied to the data of this region for a particular liquid. However, a more general treatment applicable to all liquids at one time is desirable since, as indicated by Figure 4. parameters other than the Reynolds number are involved in describing the data in this regime. Previous investigators have suggested that various dimensionless groups should be useful for the analysis of such data. These groups include the Reynolds number, the Weber number, the Froude number, and various combinations of these basic groups as used by Schmidt (23), Kaissling (10), and Rosenberg (22).

First attempts to discover functional

TABLE 2.—SUMMARY OF VELOCITY AND DRAG COEFFICIENT EQUATIONS FOR GAS BUBBLES

	TERMINAL VELOCITY	DRAG COEFFICIENT	RANGE OF APPLICABILITY
Region 1	$U_{\kappa} = \frac{2R_h^2(\rho_1 - \rho_2)g}{9\mu}$	$C_0 = 24 \text{ Re}^{-1}$	Re ≤ 2
Region 2	$U_a=0.33g^{0.50}\left[rac{ ho_1}{\mu} ight]^{0.53}R_a^{1.59}$	$C_D=18.7\ Re^{-c.co}$	$2 \leqslant \text{Re} \leqslant 4.02 \text{G}_1^{-6.714}$
Region 3	$U_{\rm c}=1.35 \left[\frac{\gamma g_{\rm c}}{\rho_{\rm c} R_{\rm b}}\right]^{0.10}$	$\begin{cases} C_D = 0.0275G_1Re^4 \\ er \\ C_D = 0.44G_2 \end{cases}$	$4.02G_1^{-0.334} \leqslant Re \leqslant 3.10G_1^{-0.335}$ $equation or 0.0000000000000000000000000000000000$
Region 4	$U_{\rm o}=1.18 \left[\frac{\gamma g g_{\rm c}}{\rho_1}\right]^{0.55}$	$\begin{cases} C_D = 0.82G_1^{0.28} \text{ Re} \\ \text{or} \\ C_D = 1.64G_2^{0.28} \end{cases}$	3.10G₁ ° 5 ≤ Re or 5.75 ≤ G₁
where	$G_1 = \frac{g\mu^4}{\rho_1 \gamma^3 g_c^3}$	$\mathbf{G}_{z}=rac{g\mathbf{R}_{b}{}^{4}\mathbf{U}^{4}{ ho_{1}}^{8}}{\gamma^{2}\mathbf{g}_{z}{}^{8}}$	

relations between the drag coefficient and the groups indicated were not successful, and an indirect dimensional analysis was required to discover the interrelation between these suggested parameters. First, it was assumed that a relation for the steady-state bubble-rising velocity of the form

$$U_{x} = f_{2}[R_{b}, \mu, \rho_{1}, \gamma, g_{c}]$$
 (19) existed where

$$f_2 =$$
 an arbitrary function

Then applying dimensional-analysis techniques it was found that this functional expression could be put in the form

$$\frac{2R_bU_x\rho_1}{\mu} = a \left[ \frac{2R_b\rho_1\gamma g_c}{\mu^2} \right]^{\epsilon} \tag{20}$$

where  $\alpha$  and  $\epsilon$  are constants to be determined from the experimental data. Fig-

ure 5 shows a plot of Region 3 data for a number of liquids in the form indicated by Equation (18). The slope of a straight line drawn through the experimental points was so close to 0.5 that it was decided to use  $\epsilon = \frac{1}{2}$  and then evaluate  $\alpha$  on this basis. This procedure led to  $\alpha = 1.91$ .

Use of these values of  $\alpha$  and  $\varepsilon$  reveals that in this region the bubble motion is independent of liquid viscosity, a feature that had been suspected by previous investigators. Further, the bubble velocity is related to the equivalent spherical radius and the liquid properties by the simple formula

$$U_{\infty} = 1.35 \left[ \frac{\gamma g_c}{\rho_1 R_b} \right]^{0.50}$$
 (21)

Equation (21) may be combined with the defining equations for the drag coefficient and the Reynolds number to

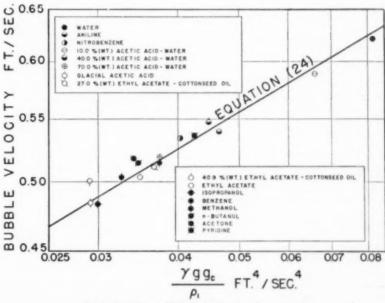


Fig. 6. Correlation of bubble velocity data for region 4.

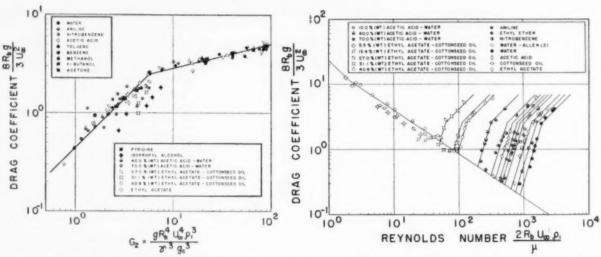


Fig. 7. Final correlation of drag coefficient data for region 3 and 4. Fig. 8. Drag coefficient for gas bubbles as a function of Reynolds number showing the recommended correlations.

obtain a relation between the two. Thus, substituting the result of Equation (21) in Equation (17) and in the expressions for the Reynolds number and solving the pair of simultaneous equations gives

$$C_{B} = 0.0275 \left[ \frac{g\mu^{4}}{\rho_{1}\gamma^{3}g_{c}^{-3}} \right] Rc^{4}$$
 (22)

For a given liquid with constant properties, therefore, the drag coefficient is proportional to the fourth power of the Reynolds number. Also, Equation (22) indicates that the Region 3 data for all the liquids should form a family of straight lines on Figure 4 with slope equal to four.

Assuming that the limit between Region 2 and Region 3 may be obtained by equating the derived relations for the drag coefficients in the two regions and solving for the Reynolds number which satisfies both relations shows that such a limiting value is given by

$$Re_2 = 4.02G_1^{-0.21} \tag{23}$$

where

 $Re_2=$  Reynolds number at the intersection between Regions 2 and 3, dimensionless

$$G_1 = \frac{g \mu^4}{\rho_1 \gamma^3 g_c^{\ 3}} \,, \,\, {\rm dimensionless}$$

This parameter,  $G_1$ , is identical with one that was proposed by other investigators (10, 22, 28) as being pertinent in describing the deviation of gas-bubble motion from the behavior of solid spheres.

Region 4. The outstanding characteristic of gas bubbles within this region is a marked tendency toward a constant rising velocity, independent of the bubble size. In fact, this characteristic was used as a criterion for distinguishing Region 3 from Region 4. Further, if it is assumed that the viscosity of the

liquid has little influence on the motion of gas bubbles in this region, the dimensional analysis result of Wigner (28) should be useful in treating these data.

From the data given in Table 1, it may be noted that for all the liquids studied except cottonseed oil and three of the solutions of ethyl acetate in cottonseed oil, a constant velocity (±5%) is attained for the largest sizes of gas bubble. In each case, the individual values were averaged arithmetically to give a value characteristic of the particular liquid. Following such a procedure, it was found that the data for sixteen liquids could be described within ±3% by the relation

$$U_{\infty} = 1.18 \left[ \frac{\gamma g g_c}{\rho_1} \right]^{0.25} \tag{24}$$

Figure 6 shows the agreement of the experimental data with Equation (24). It is pertinent to point out that Equation (24) agrees with the form predicted by Wigner's dimensional analysis (28) and with the expression of Rayleigh (20) for the velocity of wave propagation in liquids.

As before, the equation for the drag coefficient applying to Region 4 may be derived by substituting this result in the defining equations for the drag coefficient and the Reynolds number. This procedure leads to

$$C_D = 0.82G_1^{0.25} Re$$
 (25)

Then equating the two expressions for the drag coefficients for Regions 3 and 4 from Equations (22) and (25) gives the limiting value of Reynolds number for the intersection of the two regions as

$$Re_3 = 3.10 \ G_1^{-0.25}$$
 (26)

where

# $Re_3=$ Reynolds number at the intersection between Regions 3 and 4, dimensionless

The upper limit on Region 4 is estimated to be Re approximately 3000. The estimate is subject to future revision since experimental data were not taken for larger Re values in this part of the investigation.

Further generalization of the results was effected for the drag coefficient relations of Regions 3 and 4 by introducing a new variable,  $G_2$  defined by

$$G_2 = \frac{Re^4 \cdot G_1}{16} \; , \; {\rm dimensionless} \eqno(27)$$

$$G_2 = \frac{g R_b{}^4 U^4 \rho_1{}^3}{\gamma^3 g_c{}^3}$$

This product of groups cancels the effect of viscosity, which has been shown to be negligible in Regions 3 and 4. Then in terms of this new variable, Equations (22) and (25) become respectively

$$C_D = 0.44 \ G_2, \label{eq:cd}$$
 for 16.32  $G_1^{0.144} \leqslant G_2 \leqslant 5.75$  (28)

$$C_D = 1.64 \ G_2^{0.250}$$
 for  $5.75 \leqslant G_2$  (29)

Figure 7 shows a plot of Regions 3 and 4 data in the form indicated by Equations (28) and (29).

A complete summary of the equations developed for all four regions of bubble behavior is given in Table 2. Equations giving the limits of each region are also included. Figure 8 shows the complete correlation of the drag-coefficient data based on these relations.

### Comment on Results

It is realized that oversimplification of such complex phenomena as gas-bubble behavior is a dangerous practice and that a rigorous treatment of the problem is preferred to an empirical treatment. However, more detailed information on bubble shape, liquid velocity, and pressure distribution surrounding the gas bubble will be needed to pursue the theoretical treatment. Even then the mathematical difficulties of the problem may become insurmountable. This preliminary investigation has at least indicated the various parameters that must be considered in this problem. The analysis of the experimental data shows that a complex interplay of viscous, surface, gravity and inertia forces is involved.

The role of these various forces is definitely noted when the dimensionless groups denoted as  $G_1$  and  $G_2$  are examined. The group  $G_1$  involving only physical properties and the gravitational acceleration first arose in describing the limiting value of the Reynolds number for which the drag characteristics of the gas bubble become seriously different from those of solid spheres, i.e., the limit between Regions 2 and 3. Considering the factors included in this quantity  $G_1$ , it is readily shown that it is a combination of the Reynolds  $(2R_bU\rho_1/\mu)$ . Weber  $(2R_bU^2\rho_1/\gamma g_e)$ , and Froude  $(U^2/2gR_b)$  groups. Thus

$$G_1 = \frac{We^3}{Re^4 \cdot Fr} \tag{30}$$

The experimental data coupled with the physical significance of these basic groups indicate that at some complex balance between viscous, surface, gravitational, and inertia forces the gas bubble ceases to behave hydrodynamically as though it were a solid sphere. Further, for greater values of  $G_1$  the effect of viscous forces become negligible and only surface, gravitational, and inertia forces control the bubble behavior. This follows from the fact that the  $G_2$  group which was used to describe the dragcoefficient data for Region 3 and Region 4 is a combination of the Reynolds number and the  $G_1$  group such that the Reynolds number effect is canceled. Thus from Equation (27) for the definition of  $G_2$  and Equation (30) giving the composition of  $G_1$ , it is noted that  $G_2$  contains only the Weber and Froude numbers

$$G_2 = \frac{We^3}{16 \ Fr} \tag{31}$$

The contribution of the Weber group to the  $G_2$  group for Region 3 is particularly interesting. Equation (21) giving the variation of gas-bubble velocity in this region with bubble size and physical properties, when rearranged slightly, gives a constant value of the Weber number for this region

$$W_c = \frac{2R_b \rho_1 U_x^2}{\gamma g_c} = 3.65$$
 (32)

This surprising result, which arises

from an analysis of the experimental data, indicates that a constant ratio exists between the surface and inertia forces acting to deform the bubble for Region 3. It has been found that the result of Equation (32) is realized also in liquid-liquid drop systems (1, 17) with an increase of the constant by approximately 10% (We = 4.02).

One feature of this present investigation is inconsistent with the findings of Davies and Taylor (6) and Rosenberg (22), i.e., the existence of a region of bubble behavior where the bubble velocity is independent of size. This may be due to an appreciable wall effect in the present experiments involving large gas bubbles moving in a 1,03 in. I.D. tube. Experiments have been planned to supply additional information on this subject. The scope of these experiments is identical with that of the investigation on single gas bubbles in the one-tube size.\*

### Acknowledgment

The authors acknowledge the encouragement and advice in this general investigation of R. M. Boarts, head, department of chemical engineering. University of Tennessee. The work was supported partially by funds from the Du Pont Co. postgraduate fellowship in chemical engineering.

### Notation

- A = cross-sectional area of particle perpendicular to the direction of flow, sq.ft.
- $a = \text{Laplace's capillary constant, } (2\gamma g_{*}/g_{p_{1}})^{1}/g_{*}, \text{ ft.}$
- C<sub>0</sub> = drag coefficient, dimensionless
- D = total fluid resisting force, lb. force
- f = arbitrary function
- f<sub>1</sub> = arbitrary function
- f<sub>2</sub> = arbitrary function
- Fr = Froude number,  $U^3/2gR_b$ , dimensionless
- $G_i = \text{dimension!ess group, } (g\mu^4/\rho_1\gamma^3g_c^5), \text{We}^3/Re^4Fr$
- $G_2 =$  dimensionless group,  $(gR_h^4U^1\rho_1^2/\gamma^2g_c^3)$ ,  $(Re^4G_1/16)$ ,  $(We^3/16Fr)$
- g = gravitational acceleration, 32.17 ft./
  (sec.)<sup>2</sup>
- $g_e = \text{gravitational conversion factor between}$  force and mass, 32.17 (lb. mass)(ft.)/(sec.)<sup>2</sup>(lb. force)
- R = radius of curvature of spherical cap on a mushroomlike gas bubble, ft.
- $R_b = {\sf equivalent}$  spherical gas bubble radius, ft.
- Re = Reynolds number,  $2R_bU\rho_1/\mu$ , dimensionless
- Re2 = Reynolds number at the intersection between Regions 2 and 3, dimensionless
- Rea = Reynolds number at the intersection between Regions 3 and 4, dimensionless
- U = particle velocity, relative to the fluid, ft./sec.

- U<sub>e</sub> = steady state, terminal rising bubble velocity, ft./sec.
- We = Weber number,  $2R_1\rho_1U^2/\gamma g_2$ , dimensionless
- a = arbitrary constant, dimensionless
- $\beta=$  arbitrary constant, (ft.) $^{1/6}/{\rm sec.}$
- $\gamma = {
  m liquid}$  surface tension, lb. force/ft.
- $\delta = \text{arbitrary constant, (ft.)} \frac{1}{2}/\text{sec.}$
- e = arbitrary constant, dimensionless
- $\mu = \text{liquid viscosity, lb. mass/(ft.)(sec.)}$
- $ho_1 = ext{liquid density, lb. mass/cu.ft.}$   $ho_2 = ext{gas density, lb. mass/cu.ft.}$

### Literature Cited

- Ailor, R. M., B.S. Thesis, Chem. Engr., Univ. of Tenn. (1949).
- 2. Allen, H. S., Phil. Mag., 50, 323 (1900).
- Bryn, T., Forsch. Gebiete Ingenieurw., 4, No. 1, 27 (1933).
- 4. Cooper, C. M., Personal Communication (1949).
- Datta, R. L., Napier, D. H., and Newitt, D. M., Trans. Inst. Chem. Engrs., (Landon), 28, 3 (1950).
- Davies, R. M., and Taylor, G. I., Proc. Roy. Soc., A200, 375 (1950).
- Geddes, R. L., Trans. Amer. Inst. Chem. Engrs., 42, 79 (1946).
- Gorodetskoyo, A., J. Phys. Chem. (USSR), 23, 71 (1949).
- Green, S. L., "Hydro- and Aero-dynamics," Sir Isaac Pitman and Co., Ltd., London (1938).
- Kaissling, F., Forsch. Gebiete Ingenieurw., 14, 30 (1943).
- Lamb, H., "Hydrodynamics," Dover Publications Co., New York, 6th ed. (1945).
- Lapple, C. E., and Shepherd, C. B., Ind. Eng. Chem., 32, 605 (1940).
- Levich, V. G., J. Expt. Theoret. Phys. (USSR), 19, 18 (1949).
- Milne-Thompson, L. M., "Theoretical Hydrodynamics," Macmillan and Co., Ltd. London (1938).
- Miner, C. C., and Keyes, C. E., B.S. Thesis, Chem. Eng., Univ. of Tenn. (1949).
- Miyogi, O., Phil. Mag., 50, 112 (1925).
   Tech. Repts. Tohoku Imp. Univ., 4, No. 2 (1924).
- 17. Null, H. R., M.S. Thesis, Chem. Eng., Univ. of Tenn. (1951).
- O'Brien, M. P., and Gosline, J. E., Ind. Eng. Chem., 27, 1436 (1935).
- Ramsey, A. S., "A Treatise on Hydrodynamics," Pt. II., G. Bell and Sons, Ltd. London (1947).
- Rayleigh, Lord, "Theory of Sound," 1, 351-75, Dover Publications, New York (1896).
- 21. Robinson, J. V., J. Phys. and Colloid Chem., 51, 431 (1947).
- 22. Rosenberg, B., Navy Department Report 727 (1950)
- 23. Schmidt, E., Forschungsheft, 365 (Beilage zu Forsch. Gebiete Ingenieurw.) (1934).
- Stokes, G. G., "Mathematical and Physical Papers," Vol. I, Cambridge University Press, London (1880).
- Van Krevelen, D. W., and Hoftijzer, P. J., Chem. Eng. Progress, 46, 29 (1950).
- Verschoor, H., Trons. Inst. Chem. Engrs. (London), 28, 42 (1950).
- 27. Whitt, J. W., B.S. Thesis, Chem. Eng., Univ. of Tenn. (1949).
- 28. Wigner, E. P., "The Rate of Rise of Air Bubbles, AECD-1983 (1948).

Presented at A.I.Ch.E. Atlanta (Ga.)
Meeting.

Results from these experiments definitely indicate that the behavior of large bubbles is affected by the container walls. However, for each size container used to date, the equivalent of Region 4 is noted.

s described elsewhere (4), there are many possible applications of the fluidized-bed technique to the destructive distillation of coal and wood. One study of the distillation of hardwood by this method has been reported (1). Data showed that hardwood can be distilled in a fluidized bed at high rates and with no sacrifice in yield of acetic acid and wood alcohol. However, the work was exploratory in character and suffered from three major limitations: (1) excessive heat losses from the ends of the reaction vessel employed, (2) uncertainty as to yields, because of failure to obtain a complete material balance on the operation, and (3) incomplete analysis of the products. In the present work, an essentially isothermal bed has been obtained, the analyses are complete. and progress has been achieved in securing complete recovery of the products. Quantitative recovery from a batch distillation in the laboratory is difficult because at temperatures of commercial interest evolution of gas is initially high and then decreases rapidly with time.

### Equipment and Procedure

The general arrangement of the reaction vessel is shown in Figure 1. The distilling zone itself was a 4-ft. vertical section of standard 2-in. pipe, in which powdered hardwood was fluidized by a stream of nitrogen introduced at the bottom through a perforated damper. The damper was closed during actual operation, and the perforations served to distribute the incoming gas and improve the degree of fluidization. Gases evolved from the distilling zone passed through an enlarged section, which acted as a zone for settling af fines, then through a cyclone separator and a water-cooled condenser.

Heat losses from the apparatus were minimized by a nitrogen preheater and a number of resistance windings around the still, the enlarged section, and the cyclone separator, as well as by insulation. In operation, the fluidized bed was substantially isothermal, and gases evolved from the bed remained at a high-temperature level until they reached the water-cooled condenser.

The amount and composition of the noncondensable gases leaving the water-cooled condenser were determined by means of the recovery train shown in Figure 2. After removal of mist in a glass-wool trap, the gases passed through two charcoal-filled containers in series, empayed for recovery of solvent vapors. Each container was 10 in. high and of 6-in. diam., held 2000 g. of charcoal, and weighed about 3500 g. complete with charcoal and suitable fittings. A third container in parallel with the first was switched into line when the first container was about to be removed and weighed. The amount of vapor recovered in each can was determined by weighing. Vapors were then recovered by desorption under the influence of heat and vacuum, followed by condensation (still under vacuum) in a trap cooled with methyl ethyl ketone and dry ice, with a clean-up trap cooled by liquid nitrogen.

G. M. Armstrong's present address is Calco Chemical Co., Marietta, Ohio.

# Distillation of Hardwood

# in a Fluidized Bed

L. W. Morgan, G. M. Armstrong, Jr., and H. C. Lewis

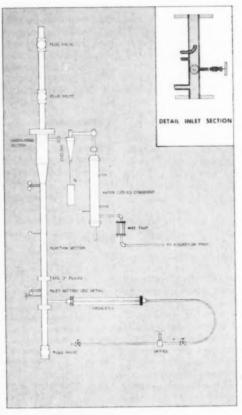


Fig. 1. Reactor and accessories.

After going through the charcoal containers, the gases passed through a gas-sampling manifold designed for obtaining samples in quick succession, then through a rotameter, and finally through a scrubber to remove carbon dioxide. The latter consisted of a 90-mm. glass tube packed to a depth of 20 in. with ½-in. Berl saddles and filled with 40% KOH. Gases were introduced at the bottom through a bubbler, and traps were attached at the top to minimize losses of KOH by entrainment.

On an industrial or pilot scale, it would probably be most economical to operate a unit of this type continuously, with a steady input of powdered wood and correspondingly steady production of distillate, gas, and powdered charcoal. However, in a preliminary study in the laboratory, batch aperation is preferable be-

cause the runs are comparatively short and, as has been shown by Kalbach (3), results of a single batch run at a given temperature can be used to predict results for all possible conditions of continuous operation at the same temperature.

In a typical run the apparatus was brought to operating temperature and the flow of nitrogen adjusted to the desired constant rate. In every case the exit nitrogen rate was observed to be from 95 to 100% of the inlet nitrogen rate, indicating the absence of any significant leaks. The charge, normally consisting of 400 g. of powdered hardwood, was introduced through a special charging device. This device was attached to the top of the apparatus only at the time of charging and therefore was always in

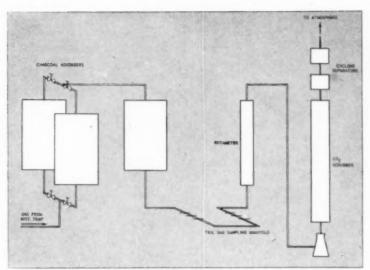


Fig. 2. Recovery train.

the neighborhood of room temperature. The device consisted merely of a container which could be subjected to nitrogen pressure, a stopper arranged to retain the charge, together with a long tube inserted through a packing gland at the top of the apparatus and reaching down to the valve at the top of the distillation zone. The charge was blown into the distillation zone in a few seconds by applying nitrogen pressure and jiggling the stopper; the valve at the top of the apparatus was then closed and the tube withdrawn without loss of product from the apparatus. Time was measured from the instant the manameter connecting the top and bottom of the distillation zone registered a change in the pressure drop. Within a minute or two after this instant, the thermocouples in the distillation zone reached the temperature maintained throughout the rest of the run.

During a run, the evolution of gas was recorded by frequent readings of the rotameter and by withdrawal of gas samples and scrubber samples for analysis. Meanwhile, the liquid collected in the receiver of the water-cooled condenser was weighed and sampled at frequent intervals. Less frequently a fresh charcoal container was substituted for the first container in line, and the latter was weighed. Normally each run was continued until the production of liquid ceased. At the end of a run, the mist was collected and sampled, both charcoal containers in line were weighed and desorbed, the KOH solution in the scrubber measured and sampled, and the charcoal withdrawn through the damper and the bottom valve and weighed.

While there was no apparent difficulty with sticking of the particles during charging or at any time in the course of a run, and the particles in the product always appeared to be completely dry and showed no evidence of having agglomerated, the charcoal did not always flow freely from the apparatus under its own weight. In the laboratory a jet of air was used to burn out residual charge.

Liquid products in the condensate receiver, mist trap, and cold traps for recovery of desorbed material were analyzed for methanol by a method depending upon formation of the nitrous acid ester, followed by volatilization

in a stream of nitrogen and reduction with potassium iodide (2). This method was found to be simple, rapid, and accurate. Acetic acid in the liquid products was determined by the usual industrial procedure of titration with alkali to a pH of 8.3. To measure the amount of carbon dioxide absorbed in the scrubber a standard double end point titration was employed with a Beckman pH meter. Gas samples were subjected to Orsat analysis.

The hardwood employed was red oak, which was reduced to powder in a mill, screened to a size range from 70 to 200 Tyler mesh, and had an average mosture content of 7.2% as charged. Because of the fibrous nature of wood, the fluidizing properties of powdered wood are undoubtedly dependent upon the method of subdividing the wood. However, no difficulty was encountered in fluidizing powder obtained in this manner. On the basis of Dimitri's work, et al. (1), 400° C. was relected as the distillation temperature. The pressure in the reaction zone was substantially atmospheric.

### Results

### Material Balance.

The order of accuracy of the data is indicated by the material balance presented in Table 1.

The entry in Table 1 that calls for explanation is the apparent high value

of 23% reported as loss. A portion of this loss, approximately 3%, is by entrainment of partially carbonized sawdust from the fluidized bed. Material entrained in this manner was recovered in the cyclone separator and weighed when the equipment was taken apart after a series of runs. No additional material was found deposited at any other point in the apparatus. Another portion of the loss is due to the fact that during the first minute of gas evolution there was a surge of gas so large and fluctuating that it could not be measured accurately with the meters available. Such qualitative measurements as could be made indicated that loss of gas during the initial surge was of the order of 5% of the charge by weight. The remaining 15% of loss is ascribed largely to deposition of a part of the charge on the walls of the tapered section of the unit, between the main reaction zone and the enlarged section above it. This material was removed after each run by admitting air, setting off a mild explosion that blew a cloud of particles out of the top of the ap-

That the 23% loss is due largely to accumulation of partially carbonized material within the apparatus during each run is indicated by element balances. The dry charge contained 49.41% C, 6.04% H, 44.05% O, and 0.50% ash, while a composite sample of the charcoal product contained 77.18% C, 3.15% H, 16.43% O, and 3.24% ash on a dry basis. With these figures and the data in Tables 1 and 2, an estimate can be made of the amount of carbon, hydrogen, and oxygen contained in the 23% reported as loss. Results of such calculations show that the composition of the 23% loss is intermediate between the composition of the sawdust charge and charcoal product.

The most likely explanation for the fact that part of the charge adhered to the walls of the tapered section is that the taper made it difficult to wrap this section thoroughly with resistance wire. As a result, the temperature of the tapered section was somewhat lower than that of the main-reaction zone and probably was never high enough to heat

TABLE 1.—DISTILLATION OF FLUIDIZED HARDWOOD FOR THIRTY MINUTES AT 400° C. MATERIAL BALANCE

Run No	1	2	4	5	6	7	8	Avg.
Yields, wt. % of dry charge. Charcoal Liquid products less moisture in charge Tail gas Gas recovered by adsorption units ‡	33.2	33.0	27.2	3.1	29.3	28.4 12 †	28.4	12
					Tota	d		. 100

 $^{\dagger}$  Composition expressed as weight per cent of the dry charge: CO<sub>2</sub> 4.7, CO 1.5, residual gas (assumed CH<sub>4</sub>) 6.1.

\$ Largely CO.

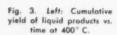
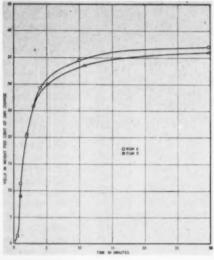
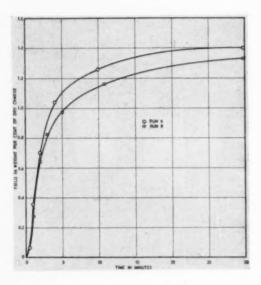
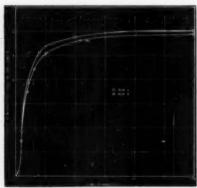


Fig. 4. Below: Cumulative yield of acetic acid vs. time at 400° C.

Fig. 5. Right: Cumulative yield of methanol vs. time at 400° C.







cold impinging particles beyond the

In a large unit, accumulation of partially carbonized material within the apparatus could be substantially prevented by proper design and heating arrangements. Therefore, the yields of gas and liquid obtained in this study are on the conservative side.

### Yield of Acetic Acid.

plastic stage.

Distillation for 30 min. at 400° C. resulted in an acid yield of 5.9%, expressed as weight per cent of dry charge (see Table 2). This compares with a yield of 6.82% total acid (including formic, etc.) reported by Merritt and White (5) for steam distillation of red oak to a final temperature of 400° C. under laboratory conditions. The same investigators report a yield of 4.70% total acid in a commercial operation with the same wood. This drop in yield is probably due to the fact that it is harder to control the temperature of a large fixed bed than it is to control the temperature of a small fixed bed in the laboratory. With a fluidized bed the reverse is true, and one may reasonably

expect plant yields to be comparable with those obtained in the laboratory.

The acid recovered by the charcoal adsorbers was approximately 1% of the total production of acid.

### Yield of Methanol.

As shown in Table 2, the average yield of methanol obtained in 30 min. at 400° C. was 1.3%, which is somewhat lower than the laboratory yield of 2.25% and the plant yield of 2.2% reported by Merritt and White (5). However, the figure of 1.3% is the result of a chemical analysis specifically for methanol, whereas plant yields are nor-

actual content of pure methanol and approximates the actual content of "crude methanol." Hence, results obtained in the present study are considered to be in reasonable agreement with Merritt and White.

The fact that these authors found a substantial check between plant and laboratory yields of methanol suggests that the yield of this compound is less sensitive to conditions than appears to be true of acetic acid. Hence, it seems unlikely that use of a fluidized bed in plant operations will result in improving the yield of methanol.

The methanol recovered by the char-

TABLE 2.—DISTILLATION OF FLUIDIZED HARDWOOD FOR THIRTY MINUTES AT  $400^\circ$  C. YIELD OF ACETIC ACID AND METHANOL

Run No	1	2	4,5,7,9 omposi		8	Avg.
Yield, wt. % of dry charge Acetic acid Methanol				6.02 1.41		5.9 1.3

mally expressed in terms of "crude methanol," a constant boiling mixture of methanol, methyl acetate and acetone. The figure of 2.25% was obtained by alkalizing the sample (6), steam-distilling it without fractionation until the sample was substantially stripped of methanol, concentrating the distillate by repeated steam distillations, measuring the specific gravity of the final distillate and comparing it with the known specific gravities of mixtures of methanol and water. This is a recognized method of analysis, particularly useful with small samples or in situations in which speed of analysis is desirable. However, because of the lack of fractionation, the methanol content as determined by this technique tends to be higher than the

coal adsorbers was about 25% of the total production of methanol.

### Effect of Reaction Time on Liquid Products.

Data on the total recovery of liquids by condensation and adsorption are summarized in Figures 3, 4, and 5. These plots show that the reaction proceeds in three stages. First, there is a lag of about three quarters of a minute in which little product is collected, partly because of the time required to bring the cold charge up to reaction temperature and partly because of the time needed for decomposition products to flow from the reaction zone to the condensate receiver. In the next four minutes reaction proceeds rapidly. Finally, there is a long period in which reaction

continues at a slow and gradually decreasing rate.

### Effect of Reaction Time on Gaseous Products.

Data on gas rates and cumulative yields at various times during the progress of a run are presented in Figures 6 and 7. That there exists a sharp peak in the evolution of carbon monoxide, as shown in Figure 6, is reasonably certain, in view of supporting data from other runs. However, the peak is so sharp that estimation of the area under the carbon monoxide curve is obviously inaccurate. The carbon monoxide curve in Figure 7, obtained from Figure 6 by graphical integration, is therefore much less dependable than the other curves.

The evolution of gas (see Fig. 6) occurred in three stages corresponding to those already observed in the data on evolution of liquid products, but with a lag of about two minutes because of the time required for the gas to travel from the condenser, where the liquid products were measured, through the cans of charcoal to the gas-sampling point and rotameter. Adding two minutes to the times observed in the production of liquid, one finds that in the case of the gas the first stage was from zero time to three minutes, the second from three to seven minutes, and the third from seven minutes on. Figure 6 shows that there was no significant evolution of gas during the first stage; during the second there was a large evolution of gas which was practically all carbon monoxide; and in the third stage there was little carbon monoxide but a significant amount of carbon dioxide and also of residual gas. These facts are striking, suggesting strongly that carbon monoxide is the only noncondensable gas formed by primary decomposition of hardwood and that it is not formed by secondary reactions. If this is so, its relatively high rate of production at the start makes it a sensitive index of the progress of primary decomposition, Similarly, the data suggest that production of carbon dioxide and residual gas are associated with secondary reactions and may be used as an index of their progress.

### Acknowledgment

The authors wish to express their gratitude for the financial support and cooperation of the Georgia Tech Research Institute and the State Engineering Experiment Station. Acknowledgment is also made of valuable assistance received from R. H. Byers and his staff. at the Georgia State Board of Health, K. G. Chesley and associates of the Crossett Lumber Co., Crossett, Ark., and M. G. Pelipetz of the United States Bureau of Mines, Pittsburgh, Pa.

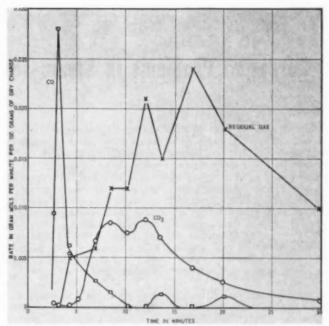


Fig. 6. Rate of production of tail gas vs. time at 400° C.

### Literature Cited

- Dimitri, M. S., Jongedyk, R. P., and Lewis, H. C., Chem. Eng., 55, No. 12, 124 (1948).
- Fischer, W. M., and Schmidt, A., Ber. 57B, 693 (1924).
- Kalbach, J. C., Chem. Eng., 54, No. 2, 136 (1947).

- Lewis, H. C., The Research Engineer, No. 1, 5 (1951-1952).
   Merritt, R. W., and White, A. H., Ind. Eng. Chem., 35, 297 (1943).
   Merritt, R. W., Ph.D. Thesis, Chem. Eng., University of Michigan (1930).

Presented at A.I.Ch.E. Atlanta (Ga.) Meeting.]

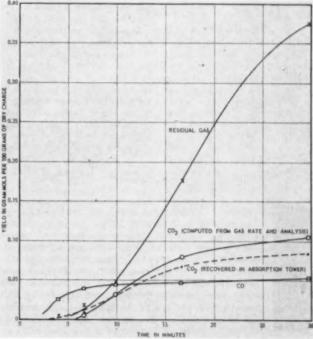


Fig. 7. Cumulative yield of tail gas vs. time at 400° C.

# Corrosion Problems in Steam-Jet Vacuum Equipment

Steam-operated vacuum ejectors are more vulnerable to corrosion than most other items of plant equipment. The average velocity of steam leaving a nozzle and expanding into the suction chamber of an ejector operating under vacuum is more than 3000 ft./sec. and in some cases more than 4000 ft./sec. This is high in the supersonic range of velocities. If the gas being handled, or the motivating steam is even slightly corrosive, the shock effect on the steam nozzle and throat at such high velocities accelerates the corrosive action. There is also an erosive action and this action is much greater when the motivating steam contains even faint traces of moisture or other impurities.

Even when the steam entering the nozzle is 100% dry it expands and cools to the dew point causing moisture formation. This moisture is usually reevaporated as the vapors are partly compressed entering the venturi throat. When one considers the short distance between nozzle and throat and the high velocity, it is apparent that there is not sufficient time for the liquid and vapor phases to reach equilibrium. The distance between nozzle and throat varies from less than 1 in. to a maximum of a few feet, indicating a time factor which is extremely small.

It can be understood therefore that corrosion is more of a problem in ejectors than in chemical-process equipment in general, where it is known to cost millions of dollars annually. In attempts to minimize corrosion, practical operating results have produced useful information. Accelerated corrosion tests which are useful in testing new materials, or in selecting the best material for processing a new chemical, are of little value in testing materials for ejectors. The normal operating condition in most

ejectors is as severe as accelerated tests, unless acceleration is accomplished by increasing the corrosive component of vapors being handled.

In cases where there is nothing more corrosive than steam, air and water, the average life of ejectors is ten years provided the motivating steam is dry enough not to cause erosion. Even with dry steam, mild steel ejectors can corrode when operation is intermittent. A multistage ejector usually operates at a relatively low temperature with the exception of the steam head on each stage and the entire last stage which discharges at atmospheric pressure. However, when a multistage ejector is shut off, it tends to become heated by the last flow of motivating steam. If a mild steel ejector is turned on and off frequently or even once a day, and left in a hot moist condition, it will slowly corrode.

For this reason, mild steel is not generally recommended for ejectors which operate intermittently, though for continuous operation steel is entirely satisfactory. Cast iron is satisfactory for either continuous or intermittent operation unless there are vapors more corrosive than steam, air and water. Steam nozzles to withstand erosion, are usually made of stainless steel or monel metal.

It might be weil to indicate the tolerances necessary on internal dimensions to maintain good efficiency. The tolerance may vary from less than one thousandth of an inch on the smaller steam nozzles, up to as much as ten thousandths of an inch or more in some of the larger throats. The only critical dimensions in the suction head of an ejector are those which provide proper alignment of the steam nozzles.

On internal throat surfaces where dimensions are critical, corrosion, un-

fortunately, tends to be more severe than in the suction chamber. For this reason throats are made sometimes of more expensive corrosion-resisting materials, while suction chambers are of cast iron. The question of how much corrosion can be tolerated on throat surfaces varies with individual conditions.

There is one case on record where the throat of a medium-sized booster ejector corroded entirely through. A new one could not be provided by the ejector manufacturer in less than eight-weeks time. The need to keep the vacuum unit in operation was most urgent and in desperation the corroded throat was removed and a piece of straight pipe was substituted as an emergency measure. To the amazement of the operators, they got about the same vacuum as with the original carefully designed venturi throat. The explanation was simple. The straight piece of pipe was substituted for the throat in the winter when the temperature of water to the interstage condensers was around 40° F. instead of the designed condition which provided for a maximum of 80° F. This meant that the condenser into which the booster ejector discharged was operating at an absolute pressure in the neighborhood of 16 mm. instead of the 50 mm. under summer operating conditions. Other things being equal, the capacity of an ejector is a direct function of the cross-section area of the smallest part of its throat. The straight pipe section had a substantially larger diameter than the smallest part of the throat. With steam from the nozzles flowing at its maximum rate and expanding to 16 mm. abs. instead of 50 mm. abs., it was able to entrain the normal quantity of vapor entering the suction. Actually it was compressing this vapor over a range of only 2 mm. or 3 mm. whereas in summertime it had to compress over a range of about 37 mm. When the correct throat was again installed, the same operation resulted with only 25% of the full steam flow.

Cold weather or cold water does not help the last stage of an ejector when it discharges to atmospheric pressure. In multistage ejectors where water or other condensable vapor is the major part of the load, the last stage, even though it is the smallest, is the most critical. The small size makes it even more critical. Slight corrosion, which



D. H. Jackson

David H. Jackson has been associated with Croll-Reynolds Co., Inc., since December, 1930, serving as chemical engineer, sales engineer, general manager and vice-president. His work has consisted largely of applying steam-jet vacuum equipment to deaerators, evaporators, deodorizers, crystallizers, vacuum-refrigerating units, etc. Previous to his Croll-Reynolds affiliation, Mr. Jackson was with the information and advertising departments of the American Chemical Society and for five years with the Elliott Co., Pittsburgh, Pa. His education includes a B.S. in chemistry from Guilford College, Guilford College, N. C., and an M.S. in chemical engineering from the University of North Carolina.

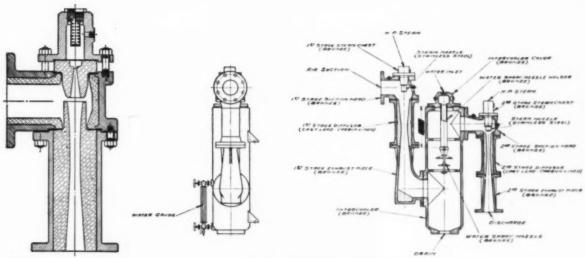


Fig. 1. Cross-sectional view of small single-stage carbonlined ejector.

Fig. 2. Section of two-stage evactor air pump.

only roughens the surface without showing any pit holes, can cause serious trouble. Central-station power plants and large industrial power plants usually standardize on duplicate final stages or two-stage ejectors.

The last stage of a multistage ejector works over a larger pressure range than other stages. Consequently it uses more motivating steam per pound of gas handled than any preceding stage. Therefore, it is frequently more economical to have duplicate final stages, or at least spare nozzles and throats, than to put enough factor of safety in the final stage to make it as dependable as the other stages.

In a study of ejector corrosion over a long period of years the most important fact we have learned about corrosion is that it is hard to predict. Experience is helpful as progress goes forward, and new materials have solved many problems. Teflon is used for nozzles and throats and even for complete ejectors within average temperature limits. New alloys have been developed and manufacturing techniques have been improved to make better use of wellknown alloys. A good example is Hastelloy. Until recently this corrosionresistant alloy was practical for ejectors only in the form of castings. With improved welding processes Hastelloy plate can be fabricated to produce any but the smallest sizes of ejectors.

Impurities in raw materials, intermediate products, or products of reaction in chemical processes, can accelerate corrosion or retard it. Oxygen is a well-known corrosive agent. It can also be a catalyst in corrosive action. One of the important applications of four- and five-stage ejectors is to pull a vacuum

down to  $50\mu$  abs, pressure or less on the internal surface of all parts of refrigerating units used in domestic iceboxes and deep-freeze units. Otherwise the oxygen and moisture occluded in the surface molecules of the metal, might later cause corrosion. When the internal surfaces are "outgassed," the refrigerant is admitted and the unit permanently sealed. A three-stage unit is sometimes used for preliminary evacuation. The approximate range of operation of ejectors of from one to five stages is shown in Table 1.

Table 1

No. of Stages (mm.)

1 760-100
2 100-12
3 12-3
4 3-0.15

0.15-0.005

Returning to the subject of corrosion in ejectors, there are fourteen different materials commonly used in ejectors. They are as follows: hard rubber; Haveg; Karbate; porcelain; Pyrex; stoneware; bronzes; chrome-plated cast iron; Duriron and Hastelloy alloys A, B. and C. Experience has been obtained with materials such as illium, tantallum, beryllium copper and higher stainless steels in the metal field, also Teflon, Synthane and other plastic materials. The plastics which use Fiberglas as a filler show promise and now are being tested. Carbon is still the most reliable material for some applications. Where metals or machinable alloys are known to be satisfactory and economical, carbon is not recommended but it is known to be usually more corrosion resistant than

any except a few of the noble metals. Some of its physical properties, such as resistance to abrasion and thermal shock are excellent. Its resistance to corrosion is also excellent. Its only weakness is its relatively low tensile strength and this can be guarded against.

Here again, recently improved manufacturing processes have been helpful. Smaller sizes of ejectors can be made with the corrosion resistance of carbon and the tensile strength of cast iron. Solid rods of carbon are used as cores in a foundry to cast protecting casings of metal. The coefficient of expansion of the metal is much greater than that of the carbon. It shrinks on cooling and makes a tight bond with the carbon. After the casings are cast the carbon is easily machined to the close dimensions required in the venturi throat and to the approximate dimensions of the suction chamber. A separate carbon nozzle with a flange is machined and bolted into place, as shown in Figure 1. In medium and larger sizes the shrinkage of the cast iron is sufficient to break the carbon. In such cases lead is often used, and owing to its malleability, it does not damage the carbon. Better cement materials and better techniques show promise of avoiding the expense of lead casings.

One of the parts of an ejector which is most vulnerable to corrosion is the elbow between a higher stage and the condenser. In many ejectors this elbow has fairly critical dimensions and is an important part of the venturi throat. Of course, it is not necessary to have an elbow at this point. The majority of interstage condensers are of the barometric or jet type, which means they are vertical. Any ejector discharging to

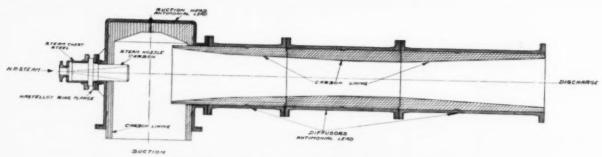


Fig. 3. Section of cast lead carbon-lined evactor booster.

such a condenser can be mounted horizontally, but practical considerations usually favor a downward or diagonal discharge. This frequently means elbows. A practical way of making such an elbow is to use a Tee fitting, as shown in Figure 2. Such a fitting can be made of rubber-lined steel or other corrosion-resistant material with a carbon block in the lower section to resist the action of high velocity and corrosion.

Figure 3 shows the design of the larger carbon lead boosters which are made in sizes up to 30-in, suction diam. The throat is made in three sections due to limitations of tensile strength of lead and carbon. The weight of a 30-in, booster ejector in these materials is approximately 14,600 lb. Many of them have been used on sulfuric acid concentrators and for miscellaneous chemical work.

Lead lining is useful for suction chambers of ejectors but is not recommended for throats where vapors impinge at high velocities. If the motivating steam is superheated and no liquid, or solid entrainment enters the suction, the corrosion-resisting properties of lead might outweigh its physical limitations, but it cannot be considered a permanent material for ejector throats and is out of the question for nozzles. Figure 4 shows a damaged lead-lined steel throat, probably from erosion. The motivating steam was superheated but the vapors entering the suction were known to contain entrained particles of dilute sulfuric acid. The throat was replaced with a rubber-lined throat with better results.

Rubber lining in throats of booster ejectors is reasonably satisfactory provided the jets, down stream from the booster, are operating and condenser water flowing so that motivating steam expands and cools in the vacuum. If water supply failure or other operating difficulty causes loss of vacuum in the booster condenser, rubber is likely to become hard and brittle and eventually flake off. Steam to the booster should be cut off promptly whenever there is a failure in condenser vacuum caused by high temperature.

The current preference of one of the

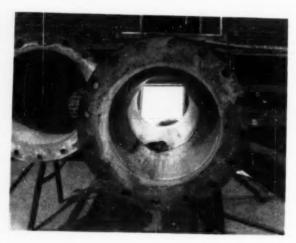


Fig. 4. Photograph shows lead lining in a booster completely penetrated by

largest users of booster ejectors on vapors containing traces of sulfuric acid, is to use 316 stainless-steel steam nozzles, lead-lined suction chambers, and rubber-lined throats. This combination seems to stand up better than many alloys that were tried previously. With reasonable handling to avoid breakage in installation or owing to thermal expansion, lead-lined carbon seems to be much more permanent, although the cost is approximately 50% more than for the stainless lead-lined rubber-lined unit.

In general, porcelain and glass are not considered too practical owing to the possibility of breakage. Since nozzle and throat have to be carefully coordinated, replacements are difficult. Ground surfaces are expensive and molded surfaces will not give as close tolerance as desirable.

We will not rate metals and alloys as to their corrosion resistance to various chemicals. This might be done if chemicals were processed individually and in a pure condition. However, most of the vacuum used in chemical processes is in some phase of a purifying process and impurities frequently cause more corrosion than the principal material which is being processed.

One sure way to help minimize corrosion is to avoid entrainment of corrosive liquids. If some superheat is provided in the motivating steam, corrosion is sure to be reduced and in some cases eliminated entirely.

There are many cases in the chemical industry where ejectors eliminate corrosion on expensive heat-transfer equipment and even eliminate such equipment altogether. One of the largest uses of ejectors is in the rayon industry in the recovery of the spin bath liquor by crystallizing out sodium sulfate so that fresh acid can be added. The spin bath liquor contains sulfuric acid and other chemicals and is corrosive. Instead of mechanical refrigeration and heat-transfer equipment to cool the concentrated spin bath to the point where sodium sulfate is crystallized, the solution is merely stirred in a large rubber-lined vessel and cooled by evaporative cooling under high vacuum. Similar processes are used in purifying titanium solutions in the production of titanium oxide. In each case the corrosion problems in the vacuum equipment are minor compared to those encountered in the old system of refrigeration and heat transfer. Ejectors also do a great deal to reduce corrosion in various forms of process equipment by reducing operating temperatures and by reducing or eliminating decomposition.

(Presented at A.I.Ch.E. French Lick, Ind., Meeting.)

# Evaporation From Liquids in High Vacuum

High-vacuum distillation differs from ordinary distillation since the separation of constituents from a mixture is in proportion to their partial pressures and the square roots of their molecular weight (3, 1), whereas in ordinary distillation the separation is, ideally, in accordance with the partial pressures alone. In practice, this distinction is far less obtrusive than the need for redesign of apparatus to provide a coextensive open path between evaporator and condenser. Even more obtrusive is the anomalous behavior of the distilling surface, which may or may not consent to evolve vapors at the calculated rate and optimum composition.

The differences have been epitomized by the chemical engineer who describes ordinary distillation as an equilibrium process, and open-path distillation as a rate process. Actually, under limiting conditions, they are substantially the same. Figure 1 represents both a rec-

Institute in 1950.

ter, N. Y.

tangular box for liquid and vapor, and also a graph of approach to equilibrium with time. Initially, the liquid is to be considered as evaporating freely into empty space. At time,  $t_0$ , the lid is placed in position, and the liquid comes into equilibrium with its vapor during a period recorded by the typical exponential curve a. At equilibrium, the number of molecules entering and leaving the liquid surface from either the vapor or the liquid phase is statistically the same. Now let the lid be moved aside instantaneously to expose again the right-hand portion of the surface to high vacuum. The molecules about to enter the liquid from the vapor are considered pushed aside by the edge of the lid. Evidently the molecules about to emerge from the liquid will still do so, and, for an infinitesimal period, the composition of emergent vapor will be the same as of equilibrium vapor. Thereafter, the contents of surface layers of distilland will be altered by depletion of

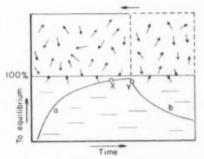


Fig. 1. Equilibrium-time diagram of liquid and vapor.

more volatile constituents, and the vapor will pass out of equilibrium along a die-away curve such as b.

It is the concern of the operator in ordinary distillation to operate at equilibrium as nearly as he can contrive, say, at point X, and it is equally his concern in open-path distillation to operate at point Y. The first requires as much time as can be spared; the second requires operating as instantaneously as possible. Failure to obtain quantitatively reproducible data in the high-vacuum still often stems from the failure to approach condition Y. Evidently positions X and Y are, generically, the same.

The qualitative difference between the two kinds of distillation concerns the evaporation coefficient, c. In the equilibrium still, with water boiling at atmospheric pressure, for instance, it can be calculated that molecules emerge from the surface 10,000-30,000 times more rapidly than they pass as steam to the condenser. The molecules re-enter the liquid as often as they leave, minus the few that escape from the vessel. Evaporation of water in the industrial boiler disturbs the equilibrium by only one part in many thousands. Evaporation cannot conveniently be done faster without encountering thermal and diffusion gradients which are too steep for practical purposes. However, if the rate of collecting distillate is kept constant as the temperature and pressure of supernatant vapor are reduced, the ratio of molecules emerging to molecules finally escaping decreases, until in the ideal high-vacuum



K. C. D. Hickman

Donald J. Trevoy, a native of Saskatoon, Saskatchewan, Canada, obtained the B.S. and M.S. degrees in chemical engineering from the University of Saskatchewan. After a short period with the National Research Council of Canada, he entered the University of Illinois, receiving the Ph.D. degree in chemical engineering in 1949. Dr. Trevoy then joined the research laboratories of the Eastman Kodak Co., Roches-

Kenneth C. D. Hickman, chemical consultant, Rochester,

N. Y., received his professional education at the Royal Col-

lege of Science. After the outbreak of World War I he

joined the Eastman Kodak Laboratories in America. In 1936

he became vice-president and director of research of Distilla-

tion Products, Inc., a subsidiary company, now known as

Distillation Products Industries. Since 1948, he has divided

his time between fundamental research on evaporation at

Kodak and a private practice in vacuum technology. In recog-

nition of the service Dr. Hickman rendered technology he was

awarded the John Price Wetherill Medal by the Franklin



still the ratio is unity; all the molecules escape.

Rate considerations, just cited, apply only if the molecules moving to and from both sides of the liquid interface actually penetrate or change phases, that is to say, if the evaporation coefficient, e, is unity. There is reason to believe that often molecules are specularly reflected from the vapor phase, while an equivalent number fail to emerge from the liquid phase. A coefficient far different from unity may make no discernible difference to ordinary high-pressure distillation because of the excess of gross evaporation pertaining. As high-vacuum conditions are neared, the evaporation coefficient becomes more and more significant and ultimately may be the controlling factor in the yield of distillate.

There has been much speculation and experiment concerning the magnitude of the evaporation coefficient, and many conflicting reports have been made. The coefficient for water (1) has been placed at 1-4%; for ethanol (2), at 10-60%; for glycerol (9), at 1%, etc. The work to be summarized here was undertaken in the belief that if evaporation could be studied under condition Y of Figure 1 from surfaces which had been mechanically cleaned an instant previously, the evaporation coefficient would prove to be unity. A convenient way of accomplishing this is to measure evaporation from a smooth liquid stream immediately after its issuance from an orifice (6). Experiments performed with 2-ethylhexylphthalate, 2-ethylhexylsebacate (7), and glycerol have shown a coefficient of unity for each liquid at the usual rates of distillation and slower. At high rates, the coefficients fell off (see graph in Figure 2), but remained substantially higher than hitherto published values.

In spite of many mechanical innovations, the most usual way of presenting a liquid for distillation is still in a pot or individual container. Here, if the surface is not vigorously agitated either by boiling or by mechanical means, it may be contaminated by any surfaceseeking impurity present. Laboratory flasks and beakers are, roughly speaking, one hundred million molecules deep, and the industrial pot still is one thousand or more million molecules deep. It would require only a minute proportion of contaminant to form a monomolecular layer of repressive material. Anomalous evaporation would be a consequence, and bumping would result from generation of vapor at pressures sufficient to disrupt the layer.

Phenomena illustrating this proposition have long been witnessed, and they can be created for study (5) in a flask half filled with high-boiling liquid, the flask being heated underneath and cooled above, and connected with a high-

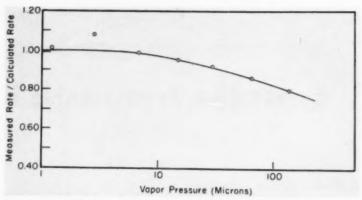


Fig. 2. Measured vs. calculated rate of projective distillation.



Fig. 3. Schizoid pattern on crude ethylhexyl phthalate (commercial dioctylphthalate).

vacuum pump. When liquids such as the plasticizers-dioctyl phthalate is a good exampleare heated in this manner, rapid distillation may ensue, and when it does, the surface is seen to be in rapid, fine-grained motion. For the highvacuum still, one can often see on the surface of the distilland much of the commotion that ordinarily takes place below the surface during boiling. Equally, however, the surface may present a placid, oily appearance and fail to emit vapor at a rate corresponding to the equilibrium vapor pressure, and then if the temperature is raised unduly, the liquid will "explade" or burst into froth in a manner well known to the organic chemist. More often, however, the liquid separates into two zones, one of which is placid and shiny, while the other is in rapid motion (see Fig. 3). If the surface is resistant, the division into two zones may be more dramatic (Fig. 4), and for such a condition the following three terms have been coined: "schizoid," to describe the divided habit; "torpid," to describe the smooth, slowly evaporating area; and "working," to describe the active area. The working area is depressed in level below the torpid by an amount corresponding with the difference in recoil pressure of their emergent vapors.

The phenomenon is not limited exclusively to high-boiling-point materials and has been observed in liquids throughout



Fig. 4. "Cast-iron" torpidity and active crater on doctored ethylhexyl phthalate.

the distillation range. Figure 5 shows butanol evaporating at -40° C, into a 6µ vacuum, and Figure 6 shows a pronounced working depression in butyl ether also evaporating at some degrees below 0° C. When, instead of a single liquid, a binary mixture is employed, the relative volatility, a, of the constituents is found to be much less over the torpid surface than over the working. An actively working surface gives vapor with nearly optimum values of both e and a, while the torpid surface may show depressed values. One is surprised to discover that even the active surface will show a variable a, according to whether the liquid is flowing so as to expand the surface or to contract it: a is greater from an expanding surface.

If this can be accepted as a fact, it follows that the rate of evolution and the composition in front of an advancing paddle should be different from that behind the paddle. In general, rate and a will be higher behind the paddle.

This suggestion has been investigated in the following exploratory experiment.

A bell jar, 6 in. in diameter, 20 in. high, was inverted as in Figure 7. The jar was closed by a top plate with a central cold finger, and connection was made to a high-vacuum pumping system. The jar was partly filled, as shown, with the liquid under test, and a stationary radial arm, fastened to a central core, was supported partially immersed in the liquid. A large 4-prong stirrer rested on the bottom of the jor and could be rotated slowly in either direction by an external magnet and a variable-speed motor. The liquid was warmed with a submerged grid of Nichrome wire. The purpose of this arrangement was to move the liquid bodily toward or away from a selected side of the radial paddle. The paddle, though stationary, was thus virtually moving.

The next problem was to measure the quantity of vapor emerging at any moment, and for this the small anemometer shown in Figure 8 was devised. A metal fan of 1 in. diam. was mounted on a shaft held between jeweled bearings. Two astatically mounted magnets produced an alternating current in a bobbin of fine wire, and silver plates (not shown) provided powerful electrical damping. The signal from the device



Fig. 5. Evaporation pattern on n-butyl alcohol at  $-30\,^{\circ}$  C.

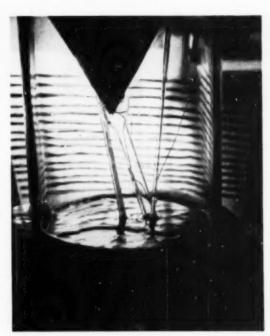


Fig. 6. Deep-working crater on crude butyl ether at -30° C.



Fig. 7. Inverted bell jar for stirrer experi-

was brought out to a vacuum-tube voltmeter, the combination, in turn, being calibrated against a source of known vapor pressure. The many constructional details and the precautions observed have been described (8). A photograph of an early model is shown in Figure 9. To complete the assembly, it was necessary to add a purification train (Fig. 10) which would enable the surface of the liquid to overflow and then distill and return to the bell jar at the will of the operator. Thus one could examine the ordinary soiled surfaces of everyday experience and compare them with continuously or progressively purified surfaces.

The emission of vapor could be measured with stirring, toward and away from the paddle, at rates arbitrarily labeled 1 to 6. Rate 1 moved the liquid at about 4 rev./min., while speed six, at 80 rev./min., all but broke the surface into spray. Figure 11 shows the kind of emission-hysteresis curve that has been encountered with various impure liquids. When the liquids are overflowed and redistilled for some days, the vapor emission increases and becomes almost insensitive to direction or degree of stirring, and approaches, but does not quite reach, the optimum calculated or the Knudsen rate.

Another way of using the apparatus is to set the stirrer at a constant direction and velocity and plot vapor emission against temperature, or, more conveniently, log vapor emission against 1/T abs. This yields curves of the type shown in Figure 12, where it is seen that the emission from a torpid surface is greatly depressed when the liquid is pushed against the paddle. When stirring is changed to the pull direction, torpidity vanishes and the opened-up surface evaporates more freely. As purging proceeds, the emission rises almost to the optimum calculated, and it is surprising to find that a nearly stagnant surface with an actively working habit can evolve vapor as rapidly as a surface that has just emerged from a liquid jet.

Evidently a considerable field remains to be explored before the chemistry and physics of the emissivity of liquid surfaces can be fully catalogued. At present, it can be stated that if the liquid is continuously overflowed, it is likely to be free from obstructive tendencies. Eumping and other anomalous events appear to be caused, not by intrinsic properties of the bulk of the liquid, but by the repressive nature of the surface skin. Accommodation or evaporation coefficients as met with in ordinary practice and ordinary states of purity are thus connected less with the chemical constitution of pure liquids than with impurities and the present circumstances and recent history of the surface.

### Literature Cited

- 1. Alty, T., Phil. Mag., 15, 82 (1933).
- Baranaev, M., J. Phys. Chem. (USSR), 13, 1635 (1939).
- Brönsted, J. N., and Hevesy, G., Phil. Mag.,
   43, 31 (1922).
- Fawcett, E. W. M., J. Soc. Chem. Ind., 758, 43 (1939).
- Hickman, K. C. D., Ind. Eng. Chem., 44, 1892 (1952).
   Hickman, K. C. D., and Trevoy, D. J., Ind.
- Eng. Chem., 44, 1882 (1952).
- Trevoy, D. J., Ind. Eng. Chem., 44, 1888 (1952).

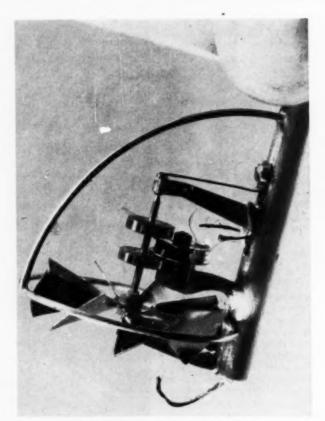


Fig. 8. Anemometer vapor probe; early model.

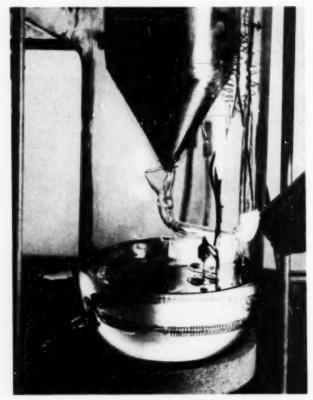
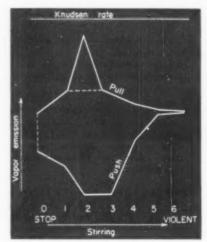


Fig. 9. Inverted bell jar for stirrer experiment; early model.

- Trevoy, D. J., and Torpey, W. A., to be published.
- Wyllie, G., Proc. Roy. Soc. (London), 197A, 383 (1949).

[Presented at A.I.Ch.E. French Lick (Ind.) Meeting.]



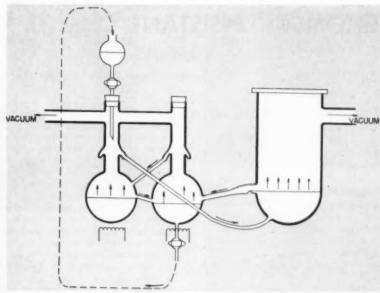


Fig. 10. Purification train for stirrer experiment.

Fig. 11. Typical hysteresis diagram of vapor emission and changes in stirring

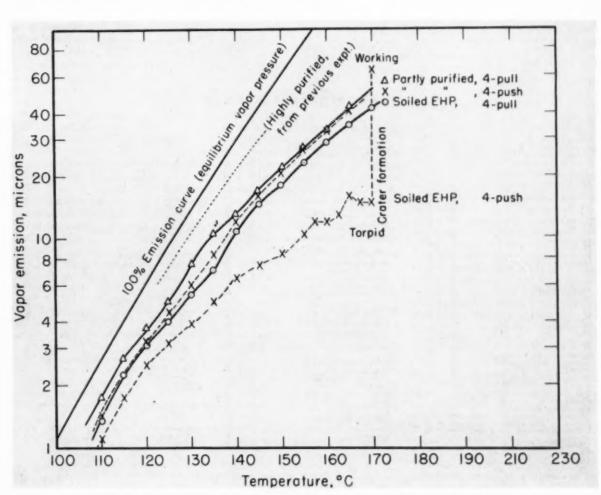


Fig. 12. Temperature-emission curves for ethyl phthalate under various conditions of purity and stirring.

# CHEMICAL RESISTANT CEMENT REFERENCE SHEET

ROBERT H. STEINER and WALTER R. PASCOE

The Atlas Mineral Products Co., Mertztown, Pa.

SULFUR CEMENTS: Filled, plasticized sulfur cement is available as homogeneous ingots which can be readily melted and used for joining brick, or bell and spigot pipe.

APPLICATION AND REMARKS: Sulfur cement is melted in a suitable melting pot at 265-290° F. and poured at this same temperature range. Bricks are placed on spacer chips, which have the same composition and uniform thickness, before pouring the

molten cement to insure bed and vertical joints at least 14 in. thick. Vertical brick walls are erected one course

at a time. The

molten cement is contained in the horizontal joints during pouring by a temporary paper dam pasted on the outside of the joints. Sulfur-cement jointed brickwork is used widely to protect impervious organic membranes in floors or tanks in the chemical- and metal-processing industries. Another major use of sulfur cement is the joining of vitrified clay and cast iron pipe. Sulfur-cement-jointed structures are ready for use as soon as the poured cement has cooled. In general, sulfur cements have excellent chemical resistance to non-oxidizing acids and acid, or neutral salts, but are not recommended for use in the presence of alkalies or organic solv-

CHEMICAL COMPOSITION: Sulfur cements are based on elemental sulfur (55-70%), inert fillers, usually silica or carbon (30-45%) a plasticizer such as Thiokol rubber (0.5-5.0%).

### A TYPICAL SILICA-FILLED PLASTICIZED SULFUR CEMENT

MECHANICAL AND PHYSICAL PROPERTIES

The following data are based on tests incorporated in a proposed tentative A.S.T.M. specification for sulfur cements:

Tensile Strength, lb./sq.in.		 	650
Comprehensive Strength, lb. sq.in.		 	6,000
Modulus of Rupture, lb./sq.in			
Adhesion to Wire-Cut Brick Surfaces, lb./sq.in		 	400
Thermal Expansion (in./in. ° F. x 10-6)		 	15
Density	***   * * -   * *     *	 	2.2

TEMPERATURE LIMITATIONS:

Because of crystalline changes occurring in sulfur at about 200° F., structures joined with sulfur cement cannot be used above this temperalure.

### CORROSION RESISTANCE

	C	H		C	14		C	н
ACIDS			ACID SALTS					
Acetic, 10%	E	E	Alum	E	E	Refinery Crudes	F	N
Acetic, glacial	p	E N	Alum Ammonium, Cl. NO <sub>3</sub> , SO <sub>4</sub>	E	EEFEE	Trichloroethylene	N	N
Benzene sulfonic	E	E	Copper Cl. SO4	6	E			
Benzoic	E	EEEZZ	Ferric Cl. SO:	6.4	E.	D. DED DD C		
		E	Nichal Cl. SOI	E	E.	PAPER MILL APPLICATIONS		
Boric	6	B.I	Nickel Cl. SO <sub>4</sub>	E	E.	Kraft Liquor	N	N
Butyric	La .	24	Stannic Cl	E.	F	Black Liquor	N	N
Chloroacetic	F	LA.	Zinc Cl. SO4	E	E	Green Liquor	N	ZZZZZE
Chromic, 10%	E.	S.e.				White Liquor	N	N
Chromic, 50%	1.	GNE	ALKALINE SALTS			Sulfite Liquor	E	E
Citric	E	E	Barium Sulfide	9.1	9.7	Chlorite Bleach		N
Fatty Acids (Ca and up)	E	F	Darium Suinde	LA	1.6	Alum	E	E.
Fluosilicie	E.	E.	Sodium Bicarbonate	E	N	Main	E.	E.
Formic	F	N	Sodium Carbonate	E				
Hydrobromic	E	E	Sodium Sulfide	N	N	PHOTOGRAPHIC INDUSTRY		
Hydrochloric	E	F.	Trisodium Phosphate	F	N	Developers	E	E.
Hydrocyanic	E	ZEEE.				accepted in the second	-	
Hydrofluoric	E 4	Ee	NEUTRAL SALTS					
Hypochlorous	E	P	Calcium Chloride	971	W.	FERTILIZER INDUSTRY		
Lactic	ě.	E.	Calcium Chloride	E	E.	General Use	E	G
Makete	E	F	Calcium Sulfate	E.	E	Silver Nitrate	G	G F E
Maleic	Ec	F	Magnesium Cl, Sulfate	E	E.	General Use	E	E
Nitric, 5%	E	E	Potassium, Cl. NOs. SO4	E	E		-	-
Nitric, 20%	E.	E.	Sodium Cl. NOs, SOs	E	E	STEEL INDUSTRY		
Nitrie, 40%	6	N					_	-
Oleic	E.	1	GASES			Sulfuric Acid Pickling	E	E
Oxalic	E.	E				Hydrochloric Acid	E	E
Perchloric	E	E	Chlorine wet	IN	N	H:SO:-HNO: Pickling	G	F
Phosphoric	E	E	Chlorine dry	1	N E			
Pierie	E	E	Sulfur Dioxide wet	E	E	TEXTILE INDUSTRY		
Stearic	E	F	Sulfur Dioxide dry	E	E	CATTLE HADOSIKI	ien.	***
Sulfuric, 50%	E	E.	Hydrogen Sulfide	E	E	General Use	F	P.
Sulfuric, 70%	E	ZEEEEEEEEZZZ				riypochlorite Bleach	B.	N
Sulfuric, 93%	C	N	ORGANIC MATERIALS					
Oleum	R.I	N		0.1	2.1	FOOD INDUSTRY		
Mixed Acida, 28% HNOs	E	N	Acetone	5.0	ZEZZZZ	General Use	E.	E3
55 % H-SO:		1.4	Alcohols, methyl, ethyl	E.	E	Breweries	E	E3
33 % HisOt			Aniline	N	N	Deteries	F	P
			Benzene	N	N	Dairies	1.	1
ALKALIES			CCle	N	N			
Ammonium Hydroxide	N	N	Chloroform	N	N	MISCELLANEOUS INDUSTRIES		
Calcium Hydroxide	N	N	Ethyl Acetate	N	N	Plating	E	C
Potassium Hydroxide	N	N	Ethylene Chloride	N.	N	Petroleum	F	N
Sodium Hydroxide	N	N	Formaldehyde, 37%	E	E	Tanning	E	E
Diddin Hydronic	1.4	1.4	Gasoline	F	N	Oil and Soap	E	GZEPE
* Carbon-Alled			Phenol	N	N	Water and Sewer	-	E

### RATINGS:

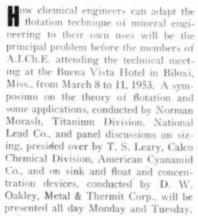
E.—No attack.
 G.—Appreciably no attack.
 F.—Some attack but usable in some instances.
 P.—Attacked—not recommended.

N-Badly attacked. C-Cold-73° F. H-Hot-190° F.

No. 18







Simultaneously with the mineral engineering techniques symposium a general technical program, presided over by A. N. Hixson, professor of chemical engineering at the University of Pennsylvania, will be held and a symposium on streamlined paper shuffling will be conducted by F. R. Fisher, Sinclair Research Laboratories, Inc. This symposium is designed to acquaint chemical engineers with the most efficient means of disposing of the volume of paper work that reaches every executive's desk. Mechanical aids and organization of paper traffic are discussed in detail by business and industrial leaders.

On Wednesday morning there will be two symposia, each from nine until twelve. The symposium on hydrometallurgical processes will be conducted by J. D. Sullivan and J. Clegg, both of Battelle Memorial Institute; and R. L. Pigford, department of chemical engineering, University of Delaware, will be in charge of the meeting on fluid mechanics. No technical meeting is scheduled for Wednesday afternoon.

Details of the entire technical program, of which Norman Spector, Vitro Corp. of America, is chairman, are on page 32. Other officers of the convention are L. B. Smith and Leon Godchaux II, Co-chairmen of the Committee on Arrangements; L. H. Stephens, Chairman of Registration; R. V. Bailey, Chairman of Publicity; J. H. Bryant, Chairman of Entertainment; R. H. Bretz, Chairman of Finance; Walter Godehaux, Jr., Chairman of Program and Transportation; T. C. Landrum, Chairman of Hotel and Meeting Rooms: H. W. Black, Chairman of Printing: and Mrs. Arthur Keller, Chairman of the Ladies' Program. The meeting is jointly sponsored by the New Orleans and Baton Rouge sections, whose chairmen are Henri J. Molaison and R. W.

### Social Program

Few social events are planned for this meeting, as it is felt that the Gulf Coast offers sufficient variety of recreation for each member to select the activities most congenial to him. On Sunday, March 8, however, the usual "get-acquainted" gathering will be a cocktail party from eight to ten at the Buena Vista Hotel, and on Monday, March 9, there will be a seafood jamboree, featuring regional specialties, at eight o'clock.

Optional activities include a bus trip on Monday, March 9, at twelve noon to Bellingrath Gardens, Mobile, Ala., which are noted for their camellia and azalea displays (\$6.00 including bus trip and admission fee), and, if sufficient





interest is shown, a boat trip on Tuesday afternoon, March 10, around Biloxi Bay to such points of interest as Deer Island, the shrimp and oyster canning factories, the shipyards, the dock of the Keesler Air Force Base, the Biloxi Yacht Club, and the near-by soldiers' home and hospital (\$2.50). For those taking the bus trip the hotel will serve brunch at eleven o'clock. Preregistration is essential for both these trips, as the busses must be ordered in advance of the meeting and the boat trip will be scheduled only if fifty or more persons register for it.

It is hoped that the ladies too will participate in these planned events.

Golf, tennis, fishing, possibly swimming, and sightseeing are other activities that may tempt the visitor to this historical old city for a brief respite during the convention or perhaps for a few extra days before or after the meeting. Golf clubs may be rented at the two public golf courses within a few miles of the hotel.

### Fishing

In regard to the fishing on the Gulf Coast at this season, about which there has been some controversy, the latest information from Biloxi indicates that there will be good speckled-trout fishing in the Gulf and fine fresh-water fishing in the bayous and that deep-sea fishing for lemon fish will be just beginning. Tackle and boats may be rented, as described in the January issue, page 17.

(Continued on page 60)

## TECHNICAL PROGRAM

### Monday, March 9, 1953 TECHNICAL SESSION NO. 1

Symposium on Mineral Engineering Techniques for Chemical Engineers—Part 1—Flotation

9:30 A.M.—"INTRODUCTION TO FLOTATION," by E. H. Crabtree, Jr., Director of Milling, the Eagle-Picher Company, Miami, Okla.

10:00 A.M.—"THEORY OF FLOTATION," by P. L. de Bruyn, Asst. Professor of Mineral Engineering, Department of Metallurgy, Massachusetts Institute of Technology, Cambridge, Mass.

10:30 A.M.—"FLOTATION KINETICS," by N. Arbiter, Asst. Professor of Mineral Engineering, School of Mines, Columbia University, New York, N. Y.

11:00 A.M.—"PHOSPHATE FLOTATION," by I. M. LeBaron, Director of Research Laboratories, International Minerals and Chemical Corporation, Chicago, III.

11:30 A.M.—"FROTH FLOTATION OF CHAL-COPYRITE AS PRACTICED AT THE LEBANON CONCENTRATOR PLANT OF THE BETHLEHEM CORNWALL CORPORATION AT LEBANON, PA.," by A. E. Anderson, Chief Metallurgist, The Bethlehem Cornwall Corporation, Lebanon, Pa.

### TECHNICAL SESSION NO. 2

9:30 A.M.—"VARIABLES AFFECTING ACTIVITY
OF MOLYBDENA-ALUMINA HYDROFORMING
CATALYST IN AROMATIZATION OF CYCLOHEXANE," by C. G. Rudershausen and C. C.
Watson, University of Wisconsin, Madison, Wis.

10:00 A.M.—"KINETICS OF CATALYTIC CRACK-ING OF CUMENE," by T. E. Corrigan, J. C. Carber, H. F. Rase and R. S. Kirk, University of Wisconsin, Medison, Wis.

10:30 A.M.—"KINETICS OF THE CATALYTIC CRACKING OF ALKYLBENZENES," by H. F. Rase and R. S. Kirk, University of Wisconsin.

11:00 A.M.—"HEAT TRANSFER IN FORCED CONVECTION FILM BOILING," by LeRoy A. Bromley, N. R. LeRoy and J. A. Robbers, Radiation Laboratory and Dept. of Chemistry & Chemical Engineering, University of California.

### TECHNICAL SESSION NO. 3

Symposium on Mineral Engineering Techniques for Chemical Engineers—Part II—Flotation

2:00 P.M.—"ADSORPTION IN FLOTATION," by C. L. Mantell, Chairman, Department of Chemical Engineering, Newark College of Engineering.

2:20 P.M.—"DETAILS OF INDUSTRIAL FLOTA-TION," by G. Gutzeit, Director, Research and Testing Laboratory, General American Transportation Corporation, East Chicago, Ind.

2:35 P.M.—"DETAILS OF INDUSTRIAL FLOTA-TION," by R. B. Booth, Senior Research Chemist, Mineral Dressing Laboratories, American Cyanamid Company, Stamford, Conn.

2:50-"LABORATORY PROCEDURES FOR FLO-

**TATION TESTING,"** by G. Gutzeit, Director, Research and Testing Laboratory, General American Transportation Corporation, East Chicago.

3.20 P.M.—"COST ESTIMATING METHODS IN MINERAL ENGINEERING," by F. Crampton, Research Engineer, International Minerals and Chemical Corporation, Mulberry, Fla.

3:50 P.M.-DISCUSSION, conducted by A. M. Gaudin, Richards Professor of Mineral Engineering, Department of Metallurgy, Massachusetts Institute of Technology, Cambridge.

### Tuesday, March 10, 1953 TECHNICAL SESSION NO. 4

Symposium on Mineral Engineering Techniques

Part III-Fine Sizing, Sizing Devices

9:15 A.M.-PANEL DISCUSSION-"FINE SIZ-ING," led by: H. R. Spedden, Head, Mineral Engineering Laboratory, Union Carbide and Carbon Research Laboratories, Inc., Niagara Falls, N. Y. Panel: R. Chelminski, Partner, Knowles Associates, New York, N. Y.; D. A. Dahlstrom, Associate Professor, Chemical Engineering Department, Northwestern University, Evanston, III.; W. A. Griffith, Minerals Research, The New Jersey Zinc Company, Palmerton, Pa.; P. J. McGuire, Director of Research and Development, Oliver United Filters, Inc., Oakland, Calif.; W. C. MacIntyre, Manager, Central Pilot Plant, Calco Chemical Division, American Cyanamid Company, Bound Brook, N. J.; E. J. Roberts, Research Director, The Dorr Company, Westport, Conn.; B. A. Rose, Vice President in Charge of Engineering, Heyl & Patterson, Inc., Pittsburgh, Pa.

10:45 A.M.—PANEL DISCUSSION—"SIZING DEVICES," led by: S. R. B. Cooke, Professor of Metallurgy and Mineral Dressing, School of Mines, University of Minnesota, Minneapolis, Minn. Panel: C. C. Coscia, Sales Engineer, General American Transporation Corporation, New York, N. Y.; W. Dyrenforth, Research Engineer, Internetional Minerals and Chemical Corporation, Mulberry, Fla.; S. E. Erickson, Metallurgical Engineer, M. A. Hanna Company, Cooley, Minn.; P. V. Mancini, Engineer, The Deister Concentrator Company, Fort Wayne, Ind.; E. J. Roberts, Research Director, The Dorr Company, Westport, Conn.; W. P. Stilz, Engineer, Link-Belt Company, Philadelphia, Pa.

### TECHNICAL SESSION NO. 5

9:30 A.M. — "REPRODUCTION OF VAPOR-PHASE HYDROGENATION CATALYST," by M. G. Pelipetz, L. V. Frank, H. H. Ginsberg and E. L. Clark, Bureau of Mines, U. S. Department of the Interior, Washington, D. C.

10:00 A.M.—"THE AEC OR CWS AIR FILTER," by David H. Northrup, Cambridge Corporation, Syracuse, N. Y.

10:30 A.M.—"PERFORMANCE OF A PULSE EXTRACTION COLUMN," by R. M. Cohen and

G. H. Beyer, Institute for Atomic Research, Iowa State College, Ames, Iowa.

11:00 A.M.—"THE DESIGN AND USE OF A TEN-KILOCURIE EXPERIMENTAL GAMMA SOURCE," by L. E. Brownell, W. W. Meinke, E. W. Coleman and J. V. Nehemias, Michigan Memorial Phoenix Project, University of Michigan, Ann Arbor, Mich.

11:30 A.M.—"THE MANUFACTURE AND REACTIONS OF HEXACHLOROCYCLOPENTADIENE," by A. H. Maude and D. S. Rosenberg, Hooker Electrochemical Co., Niagara Falls, N. Y.

### TECHNICAL SESSION NO. 6

Symposium on Mineral Engineering Techniques

Part IV-Panel Discussions:

Sink and Float and Concentrating Devices

2:00 P.M. — Panel Discussion — "SINK AND FLOAT," led by W. T. Turrall, Supervisor of Preparations, Lehigh Navigation Coal Company, Lansford, Pa. Panel: S. A. Falconer, Mineral Dressing Engineer, Mineral Dressing Laboratories, American Cyanamid Company, Stamford, Conn.; R. W. Hernlund, Sales Promotion Manager, Western Machinery Company, San Francisco, Calif.; C. S. Westerberg, Sales Engineer, Link-Belt Company, Chicago, Ill.

3:30 P.M.—Panel Discussion—"CONCENTRAT-ING DEVICES," led by A. Stanley, Head, Mineral Engineering Laboratory, Titanium Division, National Lead Company, Tahawus, N. Y. Panel: R. N. Hill, Senior Research Engineer, International Minerals and Chemical Corporation, Mulberry, Fla.; P. V. Mancini, Engineer, The Deister Concentrator Company, Fort Wayne, Ind; R. J. Piros, Research Engineer, International Minerals and Chemical Corporation, Mulberry, Fla.; E. J. Roberts, Research Director, The Dorr Company, Westport, Conn.

### TECHNICAL SESSION NO. 7

Symposium on Streamlined Paper Shuffling

2:00 P.M.—"A SOLUTION TO THE COMMUNI-CATIONS PROBLEM," by C. B. Barr, Supervisor of Communications, Sinclair Research Laboratories, Inc., Harvey, III.

2:40 P.M.—"STATISTICAL ANALYSIS OF EX-PERIMENTAL DATA BY MEANS OF PUNCHED CARDS." by C. E. Cummings and J. Sherman, The Texas Company, Beacon, N. Y.

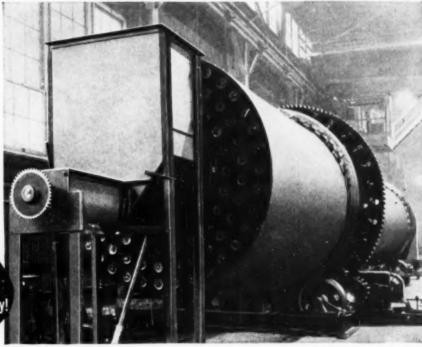
3:20 P.M.—"HOW TO ORGANIZE YOUR PAPER-WORK PROBLEM," by Frank Knox, Frank M. Knox Company, Inc., Cleveland, Ohio.

4:00 P.M.—"APPLICATIONS OF ELECTRONIC DATA PROCESSING MACHINES," by C. C. Hurd, Director, Department Applied Science, International Business Machines Corp., New York.

### Wednesday, March 11, 1953 TECHNICAL SESSION NO. 8

Symposium on Hydrometallurgical Processes (Program continued on page 60) See Louisville for CREATIVE DRYING ENGINEERING

# LOUISVILLE ROTARY DRYERS utilize 85% of all available heat in steam!



KNOW THE RESOLTS before you buy!

Ask for new treatise on subject of rotary dryers

Extremely high thermal efficiency is just one of the basic engineering advantages of Louisville steam tube Dryers. Any danger of case hardening is eliminated. Because of a very low air flow, finely divided material lost from the dryer cylinder is relatively small even though dryer may be handling unusually dusty material. Arrangements are included in each Louisville Dryer for complete and continuous removal of condensed steam . . . a unique steam

joint eliminates all thrust bearings.

Louisville Dryers are safe, automatic and economical. They require a minimum of labor, supervision and maintenance . . . and are carefully built for years of dependable service.

Write for new treatise on rotary dryers. Or call in a Louisville engineer. Have him look over your drying operation. Possibly a "predetermined", job-fitted Louisville Dryer can turn a losing operation into a profit maker.

### Other General American Equipment:

Turbo-Mixers, Evaporators, Dewaterers, Towers, Tanks, Bins, Filters, Pressure Vessels



## Louisville Drying Machinery Unit

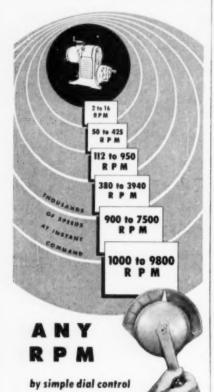
Over 50 years of creative drying engineering

### GENERAL AMERICAN TRANSPORTATION CORPORATION

Dryer Sales Office: 139 So. Fourth Street, Louisville 2, Kentucky General Offices: 135 South La Salle Street, Chicago 90, Illinois Offices in all principal cities

In Canada: Canadian Locomotive Company, Ltd., Kingston, Ontario

# U.S. VARIDRIVE -the miracle motor



Give your machines any and every speed to a split rpm within a range of 10 to 1. Varidrive accomplishes in a single power unit the functions of a motor, speed changer, gear box and controls, to occupy little more space than a fixed speed motor. The Varidrive will upgrade the quality of your work, step up your machine's output 10%, 20%, 30%.

U. S. ELECTRICAL MOTORS Inc.

Les Angeles 34, Calif. Milford, Conn.

MOTORS MAIL COUPON FOR VARIDRIVE BULLETIN

CEP-10

U. S. Electrical Motors Inc.

Box 2058, Los Angeles 54, Calif. or Milford, Conn.

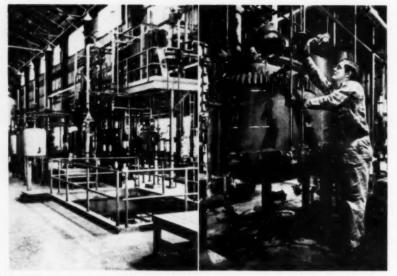
NAME

COMPANY

ADDRESS

ZONE

STATE



Above left, is the interior of the Baltimore plant showing the maze of pipes, vats and vessels needed to produce allethrin. Right, an operator is adjusting the flow of materials into the still.

### U.S.I. MAKING ALLETHRIN

Full-scale production of allethrin. synthetic insecticide, at a new plant of U. S. Industrial Chemicals Co. Division of National Distillers Products Corporation in the Fairfield section of Baltimore, Md., was revealed last month by the company.

Allethrin approximates some of the properties of pyrethrins and is one of the lowest in toxicity to humans and animals. Its greatest immediate usefulness, the company stated, will be in household aerosols and sprays designed primarily for control of flies.

Allethrin is similar in chemical structure to natural pyrethrins, obtained from chrysanthemum-like pyrethrum flowers.

Mild smelling and clear color, the material was first synthesized by Milton S. Schechter, Dr. Frederick B. LaForge and Nathan Green, chemists of the U. S. Department of Agriculture Bureau of Entomolo and Plant Quarantine. It is a homolog of Cinerin I, thus approximating one of the four major components of pyrethrins.

In spite of the chemical similarity of allethrin and pyrethrins, it was found that it could not be used as a complete replacement for pyrethrins, but will serve as a valuable adjunct to pyrethrins, helping to spread the limited supplies of the natural product.

An effective insecticide in itself, allethrin has been shown valuable as an insecticidal agent when used with certain synergists, particularly piperonyl butoxide, Sulfoxide, synergist 264 and n-propyl isome, their effectiveness being rated in the order named. Its effectiveness against insects varies with the type of synergist employed, mode of application and other factors.

In the case of aerosols, it appears that combinations of allethrin and of allethrin and pyrethrins with piperonyl butoxide will be effective and economically competitive with older formulas.

### CATALYST DEACTIVATION TO BE STUDIED

Catalyst deactivation is to be studied through a fundamental research project initiated recently by Armour Research Foundation of Illinois Institute of Technology. The program was announced in January by Kenneth W. Miller, assistant director of research.

"Although great strides have been made in clarifying the mechanism of catalyst action." Miller said in making the announcement, "the fundamental changes in catalyst structure that cause or accompany deactivation of contact catalysts are not so well understood. Here, in fact, is one of the key problems confronting catalyst technology.

"We hope that application of X-ray and electron diffraction and other techniques used in studying solid state structure will reveal clues to the deactivation mechanism. Eventually we look forward to achieving a technique for studying changes in catalysts while they are in use."

Sponsorship of the project by the Foundation is in line with its policy of making contributions to fundamental knowledge as a public service, Miller said. The support of industry will be sought when larger appropriations appear justified to achieve objectives, he added.

Associated with the study are Dr. C. H. Riesz, research chemical engineer;

(Continued on page 48)



THIS IS

GIRDLER



Built tight...built right...by Girdler

GIRDLER combines top engineering and construction skills with top quality materials to assure safe, dependable service from your new processing plant. We are especially skilled in handling processes involving corrosive materials reacting at high temperatures and high pressures. Important to the future satisfactory operation of your plant is our thorough understanding of and experience in instrumentation. Find out how Girdler's complete service can be profitable to you! Call the nearby Girdler office today.

# The GIRDLER Corporation

LOUISVILLE 1, KENTUCKY

GAS PROCESSES DIVISION: New York, Tulsa, San Francisco
In Canada: Girdler Carparation of Canada Limited, Toronta
VOTATOR DIVISION: New York, Atlanta, Chicago, San Francisco

### GAS PROCESSES DIVISION:

GIRDLER MANUFACTURES
processing apparatus

Chemical Processing Plants Hydrogen Production Plants Hydrogen Cyanide Plants Synthesis Gas Plants "Dry Ice" Plants Gas Purification Plants

ing Plants
Sulphur Plants
tion Plants
Acetylene Plants
le Plants
Ammonium Nitrate Plants
nts
Hydrogen Chloride Plants
Catalysts and Activated
Carbon
Plastics Materials Plants

# VOTATOR DIVISION: Complete Edible Oil Plants Continuous Processing Apparatus for . . .

Strained Food Shortening Textile Size
Salad Dressing Bakery Ingredients Shaving Cream
Soup Confectionaries Lubricating Grease
Margarine Citrus Concentrates Paraffin Wax
Lard Resins
Paper Coating And other Products

### THERMEX DIVISION:

High Frequency Dielectric Heating Equipment Applied to . . .

Foundry Core Baking Wood Bonding Rubber Drying and Curing PlasticPreform Preheating



### MANAGEMENT FELLOW-SHIPS OFFERED AT M.I.T.

The School of Industrial Management at the Massachusetts Institute of Technology has opened its competition for the fellowships which will be available for graduate students in the School in 1953-54.

Recent college graduates whose major studies have been in science, engineering or engineering administration and who want advanced work in industrial management are invited to apply, according to Dean E. P. Brook of the School. Fellowships will include full tuition and may carry additional cash stipends of up to \$2100 for married men and \$1400 for single men.

The fellowships were made possible by the foundation of the School under a grant made in 1951 by the Alfred P. Sloan Foundation, Inc. The School, housed in its own building, now sponsors undergraduate and graduate studies in industrial management and the Executive Development Program for those already holding responsible positions in industry.

The first year of the two-year program is devoted to basic subject matter in four areas: (1) the history and the economic and legal foundations of business activity; (2) the interrelationships of individuals and groups in industry; (3) the production, distribution, and financial structure of the economy; and (4) the operational tools of management.

The second-year curriculum is in large part worked out individually. A typical program will include advanced work in production management, marketing management, financial management, and industrial relations; a seminar in administrative policy, a seminar in public economic policy devoted to consideration of selected economic problems of major concern to industry. Approximately one quarter of the student's time in the second year is devoted to individual study of a management problem of his own choice.

Fellows will be chosen, according to Dean Brooks, on such factors as outstanding scholastic performance, demonstrated initiative and leadership ability, evidence of high moral and ethical standards, favorable personality traits, and—within certain limits—successful working experience.

Applications should be filed by March 1, 1953, or as soon thereafter as possible. Further information may be obtained from Professor Thomas M. Hill. School of Industrial Management, Massachusetts Institute of Technology, Cambridge 39, Massachusetts.

(More News on page 38)

### A LIBRARY OF ION EXCHANGE RESINS



his library, containing bottles instead of books, was founded in 1940—when Rohm & Haas chemists placed on its shelves Amberlite® IR-1—the first commercial resinous exchanger. Like many of the resins shown here, Amberlite IR-1 is already antiquated, for obsolescence is characteristic of any rapidly advancing science. Others are the Amberlite resins of the present. Some anticipate the future: they await only a need—perhaps yours—for their properties.

By consulting this library, scientists all over the world have found new ways to condition water, to isolate antibiotics, to purify sugar, to separate metals, and even to relieve human ills. You are invited to consult it at any time. It may hold for you the clue to a new process or a better process.

Amber HI LITES, a bi-monthly report on ion exchange, is available on request.

### ROHM & HAAS COMPANY

THE RESINOUS PRODUCTS DIVISION



PHILADELPHIA 8, PENNSYLVANIA



### KOLSTAD NEW CHIEF OF A.E.C. PHYSICS

Dr. George A. Kolstad, physicist with the U. S. Atomic Energy Commission in Washington since 1950, has been appointed chief of the Physics and Mathematics Branch in the AEC's Division of Research.

Dr. Kolstad received a bachelor's degree in physics from Bates College, Lewiston, Maine, in 1943 and a Ph.D. degree in physics from Yale University in 1948.

He was an employee in the Eastman Kodak Research Laboratories, Rochester, N. Y., from 1937 until 1939. During 1943 and 1944 he was an instructor at Wesleyan University, and during 1944 and 1945 he engaged in research on radar counter-measures at Harvard University. He became a member of the Yale University faculty in 1948 after taking his doctorate there, and remained at Yale until he joined the staff of the Atomic Energy Commission in 1950.

# INDUSTRIAL WASTE CONFERENCE AT PURDUE

The Eighth Purdue Industrial Waste Conference will be held on May 4 to 6, 1953, at Lafayette, Ind. Scientists from industry and government agencies will discuss mutual problems encountered in the disposal of waste materials that may result in the pollution of air or water. Papers will stress progress being made in the disposal of industrial wastes, rather than historical or review topics.

Interested persons should write to the chairman, Don E. Bloodgood, Purdue University, Lafayette, Ind. The fee for the conference will not exceed ten dollars.

Proceedings of the Seventh Conference are now available at a cost of \$1.25 from Dean A. A. Potter, Schools of Engineering, Purdue University.

# INSTRUMENTATION CONFERENCE PLANNED

The importance of instrumentation to research, production, and national defense will be the topic of a collegeindustry-government conference to be held on March 19 and 20 at Michigan State College. Sponsored by the electrical engineering department of the college, in cooperation with the National Science Foundation, National Bureau of Standards, Instrument Society of America, and the American Society for Engineering Education, the conference is open to interested engineers, who may obtain additional information from Prof. R. J. Jeffries, Michigan State College. East Lansing.

(More News on page 40)

# These are the FACTS

# complete details available on request

If you are now using COOPER ALLOY stainless steel valves you know all about the plus factors in quality and design that are yours at no extra cost. If you are using any other brand, you owe it to yourself to get the facts and make the comparison. For the full story on how competitive 2" gate valves designed for the same service differ in important service features, write for your free copy of the 2" valve Comparison Chart.





CUT OUT	AND	MAIL	COUPON	BELOW
---------	-----	------	--------	-------

...

# COOPER ALLOY

FOUNDRY CO. . HILLSIDE, NEW JERSEY

Please send along my copy of your detailed chart comparing competitive 2" stainless sheel gate Name Position

Address

City Zone State





Aerofin is sold only by manufacturers of nationally advertised fan system apparatus. List on request.

### NATIONAL SCIENCE FOUNDATION AWARDS

Approval of seventy-eight grants, totaling \$685,000, to finance the biological and physical sciences and to support studies and conferences on science and scientific education has been announced by the National Science Foundation. Grants of interest to chemical engineers are as follows:

University of California, Berkeley, F. E. Romie, department of chemical engineering: Heat Transfer to Fluids in Pulsating Flow, \$8,400.

Clarkson College of Technology, Potsdam, N. Y., H. L. Shulman, department of chemical engineering: Determination of Interfacial Area in Packed Absorption and DistMlation Columns, \$10,200.

Lehigh University, Bethlehem, Pa., A. C. Zettlemoyer, department of chemistry: A Study of Mixed Vapor Adsorption, \$5,600.

Louisiana State College, Baton Rouge, J. Coates, engineering experiment station: Thermal Conductivity of Pure Liquids and Solutions as a Function of Temperature, \$10,500.

Massachusetts Institute of Technology, Cambridge, Mass., T. K. Sherwood, department of chemical engineering: Mechanism of Mass Transfer with Chemical Reaction, \$4,600.

University of Minnesota, Minneapolis, H. S. Isbin, department of chemical engineering: Natural Convection Studies in Regions of Maximum Fluid Densities, \$5,000.

Pennsylvania State College, A. Rose, department of chemical engineering: Mass Transfer in Simple Two-Phase Systems, \$8,800.

Rensselaer Polytechnic Institute, Troy, N. Y., J. O. Hougen, department of chemical engineering: Kinetic Research in the Field of Reduction of Tungsten Oxide with Hydrogen, \$4,000.

University of Tennessee, Knoxville, H. J. Garber and F. N. Peebles, department of chemical engineering: Mass Transfer in Liquid-Gas Bubble Systems. \$6,700.

This is the second group of awards to be announced from the 1953 fiscal year budget of the National Science Foundation. During the current fiscal year the foundation has awarded \$1,340,650 for 130 grants in science.

### AMMONIA PLANT FOR UNION OIL CO.

A plant to manufacture ammonia from local natural gas is being designed and built at Brea, Calif., by C. F. Braun and Co. for Brea Chemicals, Inc., a newly organized subsidiary of Union Oil Co. The new plant, located 30 miles east of Los Angeles, is scheduled for completion in 1954 at a cost of \$13,000,-000. It will adjoin the petroleum-research center opened by Union Oil in 1952. Amoniaco Corp., a nonaffiliated company, will finance the construction.

### SOLDIER SCIENTISTS GIVE SCHOLARSHIP

Inauguration of a fund raising campaign to establish a one thousand dollar scholarship for a June 1953 graduate of the Harford County (Maryland) schools was announced last month by the Enlisted Specialists' Chemical Engineering Club of the Army Chemical Center.

The club is privately organized by soldiers assigned to this headquarters for chemical research and development under the Army's Scientific and Professional Program, aimed at maximum utilization of the talents of specially qualified personnel.

Operating with the approval of Brig. Gen. William M. Creasy, commander of this installation, the club met with Charles Willis, Superintendent of the Harford County (Maryland) Schools and the county board of education, to develop plans. The club's scholarship committee has given the County Board of Education full authority to grant the award. The only restriction is that the recipient must intend to pursue a course of study in a scientific field.

The Club stipulated that the scholarship would be awarded solely on a meritorious basis without regard to race. religion, nationality, background or sex. The person chosen to receive the one thousand dollar grant may attend the school of his or her choice and may use the money for the expenses of the initial semester or prorate it over the entire college career.

Announcement of the award winner will be made by the Harford County Board of Education concurrently with the June 1953 commencements.

### ENGINEERING FILM FROM CENTENNIAL SHOW

A 16-mm. color-and-sound film surveying man's technological progress from the dawn of history to the present time, with emphasis on American industry, has been adapted from the production "Adam to Atom" presented at the Centennial of Engineering in Chicago,

Designed primarily for the layman, the film is of interest to young students, particularly those considering engineering as a career, as it depicts the contributions of engineers to the development of modern civilization. Well-known discoveries, from the ancient wheel through the printing press and the steam engine to today's guided rockets, are glimpsed in the 29-min. film, which may be obtained without charge except for transportation from Ideal Pictures, 65 East South Water Street, Chicago 1, Ill.

(More News on page 48)



Complete filter cake stability, and the ability of the Sparkler horizontal filter plate to accommodate any combination of filter media and filter aid with

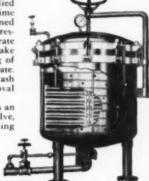
maximum efficiency is the reason Sparkler filters meet the most exacting requirements for fine filtering.

The horizontal position of the filter plates permits the use of any kind of filter paper, cloths, or screens; and any grade of filter aid without precoating of fibrous material to hold the cake on the plate. There is no distortive strain on the cake at any time even with varying pressure, interrupted flow, or complete shutdown of filtering operation.

This positive cake stability permits full attention to be given to just the right combination of filter media and filter aid to produce the required quality of fine filtration. A very thin precoat can be applied with low pressure, at a considerable saving in time and filter aid, and fine sharp filtration obtained immediately. The cake built up with reduced pressure is less dense and permits a greater flow rate than where pressure is required to hold the cake in position. No cracking, slipping, or breaking of the filter cake is possible on a horizontal plate. Complete recovery of product is obtained by "wash through" or "blowdown" of cake without removal from the filter.

The Sparkler patented scavenger plate acts as an auxiliary filter with independent control valve, filtering each batch down to the last drop leaving no hold over in the filter.

If you have a fine filtering problem our filtration engineers are ready to help you work out the solution.





Write Mr. Eric Anderson for personal attention to your particular problem.

### MANUFACTURING COMPANY

Mundelein, Illinois

Sparkler International, Ltd. Prinsengracht 876 Amsterdam, Holland

SERVICE REPRESENTATIVES IN PRINCIPAL CITIES Sparkler Western Hemisphere Corp. Mundelein, III., U.S.A.

MANUFACTURERS OF FINE FILTRATION EQUIPMENT FOR MORE THAN A QUARTER OF A CENTURY

# AUTOMATIC CONTROL

EQUIPMENT





Innouncing avalve

> Eliminates Maintenance! Reduces Worker Hazards! **Solves Installation Problems!**

> > DESIGN FEATURES

Write for your copy of our NEW ULTRAVALVE Bulletin No. 103-A Self-Lubricating • Self-Draining Positive Sealing • Simplifies Piping All in MINIATURIZED DESIGN, available in a wide variety of alloys

175 POST ROAD, WARWICK PROVIDENCE 5, R. I., U. S. A.

Cincinnati . Cleveland Kalamazoo Kansas City Kingsport, Tenn. Los Angeles New Orleans New York Pittsburgh Salt Lake City Seattle " Springfield, Mass. San Francisco St. Louis Syracuse Toledo Tulsa Wilmington, Del.

MANUFACTURED AND DISTRIBUTED BY Canada - The Guelph Engineering Co., Ltd., Guelph, Ontario

England - J. Blakeborough & Sons, Ltd., Brighouse, Yorks. . France - Premafrance, Paris



# DATA SERVICE

### CHEMICALS

1 • ORGANIC CHEMICALS. The 1953 edition of "Physical Properties of Synthetic Organic Chemicals" by Carbide and Carbon Chemicals Co. contains fifty-six new research chemicals including alpha-picoline, diethoxy tetrahydrofuran, source of succindialdehyde and four vinyl monomers. More than 320 products in family groups for easy reference.

2 • STEARATES. Technical service bulletin describes Witco Chemical Co. stearates; aluminum, cadmium, calcium, magnesium, etc. Soaps discussed in detail. Gives characteristics of each compound and industrial use. Government specifications, analytical tests, technical service reports, etc.

3 • MYLAR POLYESTER FILM. DuPont announces Mylar polyester film for industrial use. Retains flexibility at low temperatures, good insulating qualities. Tensile strength 25,000 lb./sq.in. Can be used as insulator at 200° C. and -70° C. For sound-recording, packaging, etc. Two types—colorless and translucent.

4 • ORGANIC SILICOFLUORIDES. Data sheets from Davison Chemical Corp. cover organic silicofluorides available in commercial quantities. Include methylamine, dibutylamine, ethylhexylamine, silicofluorides, etc. Used in insecticides, fungicides, mildewcides, etc.

5 • INDUSTRIAL AND AGRICULTURAL CHEMICALS. Listed in bulletin from American Cyanamid Co. are products and services for industry and agriculture. Information, with formulas, on products from various departments.

6 • PHOSPHORIC ACID. Reprint from The Dorr Co., "The Manufacture of Phosphoric Acid by the Wet Process." Contains factual information on all phases of phosphoric acid by Here is a convenient CHEMICAL ENGINEERING PROGRESS service for you — in every issue — concise, authentic reports on what is new and improved in equipment and supplies, chemicals and materials — including brief reviews of the descriptive free literature available.

To assure an easy way of keeping abreast of new equipment, new chemicals, and new developments in the field, obtain the accurate descriptions on what the manufacturer has to offer right from the manufacturer. Go through this reader service section right now—then tear out the special order card—encircle the identifying number of the literature you desire—sign and mail—that's all you have to do—no postage necessary.

sulfuric acid process. Twelve pages on equipment describe latest types. Sections on by-products, materials of construction, plus list of references.

### BULLETINS

10 • FATTY ACID GUIDE. Available from Wilson-Martin, division of Wilson & Co., Inc., wheel-form fatty acid guide for determining correct specifications and approximate composition of oleic acid, cottonseed, coconut, tallow, etc.

11 • CORROSION-RESISTANT ALLOYS. Aluminum Co. of America announces two corrosion-resistant alloys, XA54S of aluminum-magnesium for use in welded assemblies, and XC56S similar to Alcoa 56S alloy but altered to improve welding. Used for wire products.

12 • DEMISTERS. Catalog from Otto H. York Co., Inc., on demisters for the process industry; covers types, applications, engineering data.

14 • TEMPERATURE-RECORDER. Foxboro Co. bulletin on temperature-

Cards valid for only six months after date of issue

# Chemical Engineering Progress Data Service

I would like to obtain more information on the items represented by the numbers I have circled.

1 2 3 4 5 6 10 11 12 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 31 32 34 35 36 37 38 39 40 41 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82

PLEASE TYPE OR PRINT

Name Position

Company

Address

City Zone State

☐ Enter my subscription to CHEMICAL ENGINEERING PROGRESS for one year. Bill for \$6.00.

February 1953

Mail card for more data ▶



# DATA SERVICE

recorder construction. Shows component parts, etc. Section on selecting correct thermal system for control of process variables.

- 15 LIQUID-HANDLING. Filters, mixers, cappers, fillers, pumps for handling liquids in the chemical, pharmaceutical, food, cosmetic industries described in catalog from Ertel Engineering Corp. Illustrated, contains engineering data.
- 16 STEAM BOILER PLANTS. Catalog of ¾ to 7 bhp. automatic, gas-fired, steam plants by Eclipse Fuel Engineering Co. For heating jacketed kettles, tanks, presses, pasteurizers, sterilizers, etc., and general process industry use. Specifications, dimensions, diagrams.
- 17 PUMPING VOLATILES. Vertical pumps for volatile fluids by Johnston Pump Co. Cross-section drawings. Features higher speeds, steep head-capacity, stability, nonoverloading power characteristic.
- 18 LIQUEFIED-GAS EQUIPMENT. Catalog from Mechanical Division, Arthur D. Little, Inc., summarizing production, handling and storage of liquefied gases. Covers liquefiers, refrigeration, generators, air coolers. Illustrated, physical and operating data given.

- 19 INSTRUMENT HANDBOOK. Minneapolis-Honeywell Regulator Co. engineering handbook on Electronik recorders and indicators for temperature, flow, humidity, liquid level, and other variables. Charts, scale, and illustrations.
- 20 DESIGNING EXPANSION JOINTS. Revised design guide from Flexonics Corp. on corrugated expansion joints. Easily installed, compact, maintenance-free. Diagrams, specifications for various materials, deflection charts, etc.
- 21 POLYMERIZATION PLANTS. Bamag polymerization plant, description of fish oil plant for manufacture of edible oils without fish taste or odor. Also oils for lac, dyes, frying, soap, etc. Applied to vegetable oils. General Industrial Development Corp.
- 22 BOILERS AND CONDENSERS. Doyle & Roth Mfg. Co., Inc., leaflet on standard vertical thermosyphon reboilers and reflux condensers. Stainless steel. Specifications and schematic view.
- 23 FILTERS. Dollinger Corp. liquid filters for oils, water, chemicals, coolants. Adaptable to removal of rust, dirt, pipe scale, etc., from process

liquids, including acetone, fuel oil, pharmaceuticals, etc. Sizes 1 to 138 sq.ft. of filter area, pressure 150 lb.

- 24 COMPRESSORS. Cooper-Bessemer Corp. multistage, multicylinder compressors, 100 to 5000 hp., 250 to 514 rev./min. Powered by electric motors or internal combustion engines. Illustrations, diagrams, specifications and other data.
- 25 ROUND PROCESSORS. Multipurpose, heavy-duty processing vats, called round processors, covered in Cherry-Burrell Corp. bulletin. Capacities 300 to 1000 gal. for heating, pasteurizing, mixing, etc., as well as for refrigerated storage. Stainless steel. Photographs, line drawings, other data.
- 26 TRANSITION ENGINEERING. Cambridge Corp., an affiliate of Carrier Corp. and Arthur D. Little, Inc., announce new industrial service, transition engineering, to bridge gap between research and development, and commercial production.
- 27 WASTE TREATMENT. Builders-Providence, Inc., "Industrial Waste Treatment Guide." Shows types, or combinations of unit treatment processes for more than fifty wastes. Also equipment.
- 28 PROCESS EQUIPMENT. Blaw-Knox Co. line of autoclaves, quickopening doors, extractors, cookers, resin plants, etc., for use with process equipment. Also equipment for distillation, gas absorption, solvent extraction, etc. Sizes and pressures, dimensions, illustrations, etc.
- 29 SELECTING CENTRIFUGAL PUMPS. Allis-Chalmers Mfg. Co. guide to centrifugal pump selection. Capacities 10 to \$500 gal./min. Axial- and mixed-flow, close-coupled, double-suction, electrifugal pumps. Also pumps for marine, multistage and process use. Tables, illustrations, etc.





BUSINESS REPLY CARD

Chemical Engineering Progress
120 East 41st Street

New York 17,

**New York** 



USE THIS CARD FOR FREE DATA



# DATA SERVICE

- 31 FLEXIBLE HOSE. Flexible hose and tubing by American Brass Co. Seamless and stripwound construction. Engineering data, specifications, and illustrations.
- 32 PURIFIERS. Steam- and air-processing purifiers by V. D. Anderson Co. Covers information for purchase, layout, and installation. Selection charts by specific industry, specifications, etc.
- 34 PLANT LOCATION. "Factors Influencing Plant Location," brochure from Walter Kidde Constructors, Inc. compiles and answers basic management questions. Sections on purpose, procedure, value, etc.
- 35 PIPES AND FITTINGS. Jacketed cocks, pipes, and fittings by Parks-Cramer Co. For use in keeping viscous material fluid where heating medium, hot water, oil or steam, is circulated through jacket. Pipe 11/4-8 in. I.D. Cocks and fittings 11/4 x 2-8 x 10.
- 36 ANNIN VALVES. The Annin Co. line of valves illustrated and diagrammed. Single-seated separable body, for varied applications. Cast with balanced wall sections, withstands pressures to 3000 lb./sq. in. Unrestricted flow, positive plug and seat alignment. Corrosive resistant. Formulas, capacities, etc.
- 37 CRUSHERS. Brochure covers complete line of Pennsylvania Crusher Co. Various methods of mechanical reduction fully described and illustrated.
- 38 AMPCO ELECTRODES. Ampco Welding News, third-quarter issue, describes and illustrates fifty-two welding applications using Ampco-Trode and Phos-Trode electrodes. Also features Ampco safety tools.
- 39 COMPRESSORS. Compressors by Pennsylvania Pump & Compressor Co. Illustrated leaflet. Features compressed air and gas free of oil vapor.
- 40 HEAT EXCHANGERS. Heat exchangers fabricated from impervious graphite. Falls Industries, Inc. Bul-

- letin covers range of seven to series of 241 tubes. Single- and double-pass types. Leaflet illustrated, diagrams, sizes, etc. Applicable to acetic acid, carbon disulfide, hydrochloric acid, etc.
- 41 SHELL MOLDING. A manual on the Monsanto Chemical Co. shellmolding process. Contents include synopsis of shell-molding process and merits, equipment requirements, material requirements, limitations, etc. Fineness tests of various sands, chemical analysis, photographs.

### EQUIPMENT

- 45 FILTER PAPER. Laboratory and industrial filter paper sample book from Eaton-Dikeman. Chart of physical characteristics.
- 46 PUMPS. From The Galigher Co., Vacseal rubber-lined solid- and acid-handling pumps. All metals, 2 to 8 in. sizes, capacities to 3000 gal./min. Virtually glandless. Suction lifts of 10 to 12 ft.
- 47 MANIFOLDS AND DUCTS. Corrosion-resistant manifolds and ducts from American Agile Corp. Fabricated from polyethylene or unplasticized polyvinyl chloride. Welded construction, square or round shapes, fully rigid.
- 48 STEAM TRAP. High-capacity impulse steam trap by Yarnall-Waring Co. Pressures 1 to 300 lb. Capacities—1½ in. from 3000 to 24,700; a 2-in. from 4670 to 37,400 lb./hr. discharge of condensate. For drainage on heat-exchangers, reboilers, stills, polymerization units, petroleum and chemical plants. Dimensions, weights, prices quoted.
- 49 FLOATING THERMOMETER. Weston Electrical Instrument Corp. All metal floating thermometer. Accurate to ±1° F., range 50° to 150° F., stem length 5 in. Stainless steel.
- 50 MOTOR CONTROLS. Explosionproof motor controls of Crouse-Hinds Co. Features built-in push-button

- stations and selector switches; additional back and horizontal throughfeed conduit entrances; reset mechanism; neoprene gasket protection of upper cover joint against weather; increased wiring space.
- 51 HEAT-EXCHANGERS. Downington Iron Works, Inc., division of Pressed Steel Tank Co., catalog. Details heat-exchanger section, performance, mechanical design, tube sheet layout with tables, illustrations, etc. Gives partial analysis of A.S.M.E. code for unfired pressure vessels. Information on facilities.
- 52 MOTOR CONTROLS. Low-cost packaged drive of electronic adjustable speed control unit driving series motor. Arrow-Hart & Hegeman Electric Co.
- 53 PROPORTIONING PUMPS. Neptune Pump Mfg. Co. chemical feed unit for treating boiler feed-water. Pressures to 1000 lb./in. capacities to 15 gal./hr. Vertical motion eliminates settling of precipitates and consequent wear. Crosshead 1¼ in. diam., 2 in. long.
- 54 BAG-HOLDERS. Manual or airoperated bag-holders with swell, cable, or cam grips. Hold burlap, cotton, paper or lined bags, diameters 7 to 16 in., circumferences 22 to 501/4 in. Sufficient grip to prevent dust and splashing. Richardson Scale
- 55 ULTRAVIOLET UNIT. Cooper Hewitt Electric Co. all purpose ultraviolet laboratory unit. Built-in storage and carrying case. Energy supplied by 400 w. high-pressure quartz mercury arc lamp enveloped by clear, fused quartz, for 110 v. 60 cycle. Other voltages and frequencies available.
- 56 PRESSURE GAGE. Press-I-Cell, pressure meter by Fischer and Porter Co. Measures pressure to one part in 5000 on 600-in. scale. Interval of 1/16 in. represents 1/10,000 of full range. Range 1 atm. abs., 400-in.

water column, 150 in. Hg differential. Two models. Repeatability rating one part in 7000.

- 57 TUBE-EXPANDER. The Vernon-Ormeco method expander for use on tube sheets described in bulletin from Vernon Tool Co., Ltd. Explanation of method, illustrations, diagram, etc.
- 58 TEST CHAMBER. High- and low-temperature and humidity chamber. Unit ranges from +250° F. to -100° F., has accelerated pull-down, controller scale from -200° F. to +400° F., multipaned observation port, etc. Webber Appliances Co., Inc.
- 59 TEFLON EXTRUDED TUBING. Extruded tubing from Teflon by Ethylene Chemical Corp. Tolerances as close as .005 in. Continuous density.
- 60 ION-EXCHANGE REACTOR. Enley Products Co., Inc. has developed new reactor for entire field of ion exchange, plus removal of solid and gaseous media. Available in two sizes and three heights, capacity up to 12,000 gal.
- 61 PRESSURE TRANSDUCER. For measurement of rapid pressure surges and high-frequency-pressure pulsations in processing equipment, hydraulic control systems, etc., new pressure transducer from Consolidated Engineering Corp. Transducer Division.
- 62 BLOWER. For removal of fumes, dust, smoke, sawdust, etc., a new high-pressure blower from Standard Electric Mfg. Co. All-aluminum, moves up to 450 cu.ft. air/min. Powered by 1/6 hp., 115 v. single-phase ac., 3450 rev./min. motor.
- 63 FLOW METER. For measuring air or gas flow, or recording ratios, new diaflow meter from The Hays Corp. For industrial furnaces and sewage-disposal plants. No water, oil or mercury required, leveling eliminated.
- 64 INDICATOR-CONTROLLER. Industrial Instruments, Inc. new indicator controller for industrial control and measuring solution concentrations. Four separate electric switches for alarm and control. Air control 3 to 15 lb./sq.in. for remote operation, or combination of electrical and air.
- 65 REDUCTION GEARS. Elliott Co. announces new line of high-speed

reduction gears for mechanical drive turbines. Available in built-in or coupled designs, feature precision hobbed double helical gears, etc. Gear ratios up to 5:1 for built-in, to 8.5:1 for coupled.

- 66 ELEVATOR BUCKET. A take-up and water-tight bucket elevator boot, new development from Beaumont Birch Co. Water-tight boot keeps material dry even with water in bucket. Important for handling dry chemicals in plants located on rivers.
- 67 LIGHTING FIXTURE. Developed by Crouse-Hinds Co. new 300/500 w. dust-tight lighting fixture. Underwriter approved, for use in Class II, Groups E, F, G hazardous locations.
- 68 BOILER-BURNER UNITS. Iron Fireman Mfg. Co. and Kewanee-Ross Corp. jointly announce new line of boiler-burner units. Available for high-pressure steam and water, sizes from 52 to 304 hp., 125 to 150 lb. working pressure.
- 69 GRAPHITE ANODE. Cathodic Protection Service new graphite ground anodes. Strong lead secured to anode by new attachment permits heavy loads on the lead. Service information available.
- 70 BARREL PUMP. Engineered Equipment Co. barrel pump for handling fluids such as viscous or oily liquids, motor oil, coolants, ink, thinners, etc. Fits ¾ in. suction pipe, empties 55 gal. drum in 8 to 10 min.
- 71 PACKING GLANDS. Designed as a standard seal for entry of small dial type thermometers, thermocouple wells, pitot tubes, etc., by Conax Corp. Stainless steel for maximum corrosion resistance and interchangeability. Standard 1/8 in. I.P.S. threaded connection. Sizes 3/32 in. to 3/16 in.
- 72 PRESSURE TRANSMITTER. King Engineering Corp. new pressure transmitter for pneumatically operated instruments measuring liquids and gases requiring positive seal. Can be used with most fluids including acids, solvents, food products, etc. Leaflet gives details, sizes.
- 73 PLASTIC PIPE. Glass fibre-reinforced thermosetting plastic pipe manufactured by Reflin Co. Allows higher pressures, better resistance to heat and impact loads, larger sizes.

Resistant to most salts, acids, hydro-carbons, etc.

- 74 FORK TRUCK. Electric fork truck, 2500-lb. capacity, 7 miles/hr. from Baker-Raulang Co., Baker Industrial Truck Division.
- 75 PURIFIER. For removal of dirt, moisture, etc., from steam, gas and vapor lines, the Hi-eF purifier from V. D. Anderson Co. Entrainment removed through stationary centrifugal separating element. Sizes up to 24 in. for pressures up to 600 lb./sq.in. gage.
- 76 ACCELEROMETER. Thimble-size accelerometer new with Endevco Corp. For measuring shock and vibration. Small components can be tested under actual or simulated shock.
- 77 UNITIZED BATH. Tailor-made constant temperature baths from Fisher Scientific Co. Bulletin on the subject describes and illustrates system.
- 78 FRACTION COLLECTOR. Unattended fraction collection with new automatic collector from Microchemical Specialties Co. With flowing liquids, eliminates manual collection. Interval timer indexes reel and stops each tube. Reel has sixty-four stops. Optional diverter arm for dispensing to all three rows in one setting.
- 79 PORTABLE pH METER. Powered by only three ordinary radio batteries giving 2000 hr. service new portable pH meter from Photovolt Corp. Illustrated leaflet.
- 80 DRUM FILLER. Automatic and capable of filling 1000 drums of 53-55 gal. capacity in eight hours by single operator, drum filler announced by Rucker Co. Useful in all industries.
- 81 PORTABLE CUTTING MACHINE. From H. Maimin Co., Inc., a heavy-duty portable cutting machine for cutting up to a 2-in. slab of 95 durometer rubber. Self-contained, has water-feed attachment to lubricate and cool cutting blade.
- 82 CONVEYOR BELT. New-type conveyor belt from New York Belting & Packing Co. For use where conveyor belts are subject to severe ripping or tearing action, in quarry work, handling of metallic ores, etc.



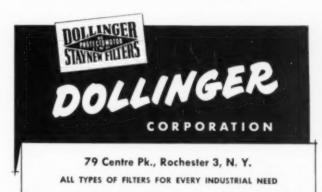
SEND FOR THIS

12-PAGE BULLETIN D-1L

JUST OFF THE PRESS

This bulletin contains specifications, engineering and performance data, photos and descriptions of recommended types of filter media, check list of liquids that can be filtered and other helpful data.

- CUTAWAY DRAWINGS
- LIST OF LIQUIDS THAT CAN BE FILTERED
- . GENERAL SPECIFICATIONS
- PERFORMANCE DATA
- . TYPES OF FILTERING MEDIA
- INSTALLATION PHOTOS AND DATA
- . PROJECT DATA SHEET







FOR SUPPLY-WATER OR TRADE-WASTE TREATMENT



Hardinge THICKENERS or CLARIFIERS have solved problems for the following industries with water treatment, waste-disposal or by-product recovery difficulties: coal, paper, oil, glass, lime, stone, sand, carbon black, meat packing, rubber, domestic sewage, and others.

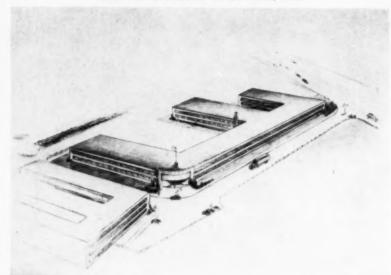
Available for steel, tile, wooden or concrete tanks up to 200° diameter with the famous "Auto-Raise" feature to prevent scraper breakage. Write for Bulletin 31-D-40.

# HARDINGE

YORK, PENNSYLVANIA — 240 Arch St. Main Office and Works

NEW YORK 12 • SAN PRANCISCO 11 • (HICAGO 6 • HIBBING, REINH • 1080NTO 1

122 E 43 nd St. 34 Caldierna St. 205 W Wader Dr. 2016 Fryt 8xx 208 8xy St.



Immediately adjacent to its recently constructed mechanical division building, is the 60,000 sq. ft. research laboratory of Arthur D. Little, Inc., pictured above. Experimental work in chemistry, chemical engineering, physics, and new products and production methods will probably be housed in the building by Jan. 1, 1954.

### A.D.L. PLANS NEW RESEARCH BUILDING

New research facilities for Arthur D. Little, Inc., Cambridge, Mass., will be erected on the Concord Turnpike in West Cambridge and will be ready for occupancy by the end of the year. Earl P. Stevenson, president of the firm announced last month. Mr. Stevenson stated that construction would begin in April.

The building will be situated in a new industrial area, immediately adjacent to a building recently completed for Little's mechanical division and occupied on Jan. 1. It will be a two-story, E-shaped structure of sixty thousand square feet. Present plans are that it will house the company's experimental operations in physics, chemical engineering, new-product development, and production methods. Additional land is available for further construction. The company's headquarters and its technical-economic research will continue at the present location on Memorial Drive, Cambridge.

Memorial Drive, where Little's activities were concentrated until recently, has become known as Research Row because it is the site of many other organizations engaged in both fundamental and industrial research. In announcing the plans for the new building, Mr. Stevenson said "It is with real regret that we are moving an important share of our operations away from Research Row, for Arthur D. Little, Inc., was one of the first industrial occupants of the Row, However our operations have now

reached such a scope that we cannot hope to house all of them in this popular section. We have felt it best to keep the administrative and technical-economic staff close to the other research organizations and to the downtown area and to locate the experimental operations in West Cambridge . . . ."

### MARSHALL IS PERMANENT SECRETARY OF E.J.C.

T. A. Marshall has been appointed permanent secretary of Engineers Joint Council and will continue to serve as executive secretary of the Engineering Manpower Commission. The Council, a federation of the national societies representing the five basic branches of engineering, formerly had a rotating secretaryship with the secretary of each of the constituent societies serving one-year terms. The new appointment discontinues the rotation of this office.

Mr. Marshall is a graduate of Georgia Tech. He was formerly with the Metropolitan Life Insurance Co.

### CATALYST DEACTIVATION

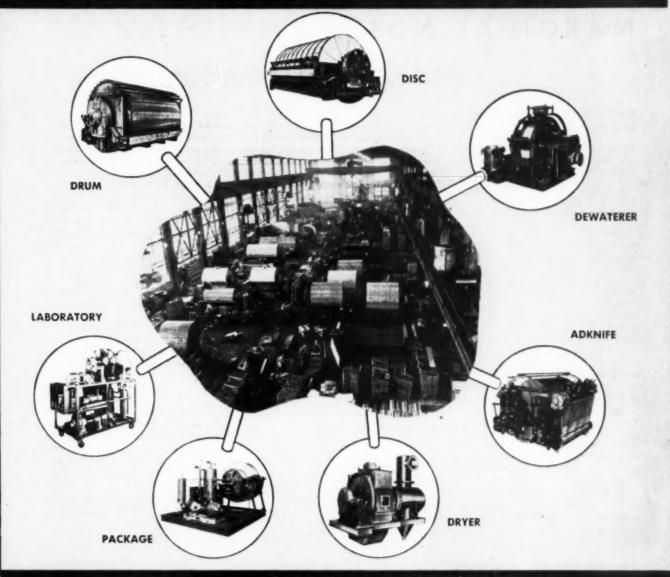
(Continued from page 34)

Dr. F. V. Schossberger, research physical chemist: and Dr. K. L. Yudowitch, supervisor, Physics of Solids section.

Prof. V. I. Komarewsky, director of the Catalysis Laboratory at Illinois Institute of Technology, is consultant to the group. The project is administered by Miller and Dr. J. E. Barkley.

(More News on page 54)

# EIMCO VACUUM FILTERS



# FOR THE PROCESS INDUSTRIES

Production of all types of continuous vacuum and pressure filters from our new filter plant has reached an all time high. In addition to production these facilities have given us an opportunity to try out new techniques, work out better ways of producing the special equipment your plant will require. We can now recommend new materials we've been experimenting with in our laboratories.

Write for information on the type of filtration equipment you'll be needing — your problem will be kept in strictest confidence. Eimco makes

all types of vacuum filters and we'll tell you about the one we think will do the job best. It'll be the best filter you can buy at any price.

# EIMCO

### THE EIMCO CORPORATION

The World's Leading Manufacturer of Vacuum Fifteetium Taujument EXECUTIVE OFFICES AND FACTORIES - SALT LAKE CITY 10. UTAH U. S. A.

### BRANCH SALES AND SERVICE OFFICES:

NEW YORK, S1-32 SOUTH STREET . CHICAGO 3319 SOUTH WALLACE, STREET ERRAINGHAM ALA STAR FAFFTTE AVE . DULUTH MINN 316 E SUPERIOR ST FAND TRANS MILES BURDING . REPRETET, CALL 632 CEDAR STREET RELIGIOGO GALHO 102 ORVISION ST . FONDON W. I HYGLAND 189 PICCADELLY

IN FRANCE SOCIETE EIMCO PARIS, FRANCE IN ENGLAND EIMCO GREAT BRITAIN; LTD. LEEDS 17 ENGLAND IN ITALY EIMCO ITALIA S.P.A. MILAN ITALY

# MARGINAL NOTES

News of Books of Interest to Chemical Engineers

It's Still a Yarn Whether Fiber or Fabric

Textile Chemicals and Auxiliaries. Henry C. Speel, Ed. Reinhold Publishing Co., New York (1952). 493 pp. \$10.00.

Reviewed by A. F. Tesi, Assistant to Technical Director, Celanese Corporation of America, New York.

This treatise on textile chemicals and auxiliaries is the result of the collaboration of twenty-five different contributors.

As the name of the book implies, the emphasis is on the chemical materials used in the textile industry rather than on the structural properties of the fibers and the engineering aspects of the conversion of the fiber to finished fabric.

Any chemical engineer who has an interest in textiles, whether it be in the manufacturing of the fibers or the processing and finishing or fabrics, should find this book of value, since it covers practically every conceivable aspect of the industry. The book is divided into two parts. The first part is concerned with the nature and processing of fibers and fabries, and includes not only much information on the physical and chemical characteristics, but includes chapters on such subjects as chemical aspects of textile dyeing and printing, fabric stabilization, and technology of pigment application. Part two, which is composed of sixteen chapters, concerns itself with the raw materials used in fabric processing. This part contains chapters that run all the way from water consumption and purification to such things as mothproofing and flameproofing. This part of the book covers the application and properties obtained from such commonly used finishing agents as natural starch gums and glues, as well as some of the less widely used synthetic resins and chemicals employed to produce special effects.

The book covers the subject quite completely as shown by the fact that there are almost 600 references, and practically all phases of dyeing, finishing and fabric-processing have been included.

While this book is not written primarily for the chemical engineer, it contains a world of information and should serve as an excellent reference book for any chemical engineer interested, in any way, with fiber manufacture as well as any phase of fabric-finishing operations. It particularly supplies the supplementary elicinical compositions and reactions essential for an up-to-date knowledge of the processing of available yarns and fabrics.

### The Wisdom That Lingers

Engineers and Ivory Towers. Hardy Cross. Robert C. Goodpasture, Ed. McGraw-Hill Book Co., Inc., New York (1952). 141 pp. \$3.00.

Reviewed by Thomas K. Sherwood, Professor of Chemical Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

The literature on engineering education and the nature of engineering is most voluminous, yet there is so little of it that is worth reading. It is a delight, therefore, to find this small book on the philosophy of engineering and of engineering education, written by an elder statesman famed both as a teacher and as a creative engineer. It is full of wisdom, often put down as pithy epigrams which are certain to be widely quoted. Engineering education would benefit greatly if some philanthropist were to place a copy in the hands of every professor of engineering. Practising engineers will get a lift from Professor Cross' outline of the techniques of engineering practice, his hard-boiled analysis of the value of theory, and his vision of engineering as service to mankind. This collection of excerpts from Professor Cross' writings, well arranged by the editor, ranks with the late President Wickenden's discussions of engineering, and in many ways is more understandable.

### To Keep On Hand

Handbook of Chemistry. Norbert Adolph Lange. 8th edition. Handbook Publishers, Inc., Sandusky, Ohio (1952) 2014 pp., \$7.00.

Reviewed by D. H. Killeffer, Consultant, Tuckahoe, N. Y.

This well-known and much-used handbook needs little comment. Its present, eighth edition follows the familiar pattern of its predecessors and presents a wealth of data in convenient form that would be difficult to find if one had to look up original sources. New tables of data are added on: Ionization Potentials of Elements: Classification of Clay Minerals: Glossary of Inorganic Chemical Nomenclature; Titrimetric Indicators; Molar Equivalent of a Liter of Gas at Various Temperatures and Pressures, and Density of Moist Air. Some of the old tables have been dropped: Logarithms of Atomic Weights, Heats of Fusion of Organic Compounds, and Synchronistic Table of Chemical Journals. A great many familiar and muchused tables have been amended. A maroon binding differentiates this edition from its predecessors.

Now as in the past this valuable compilation will have high usefulness as a time- and patience-saver at the right hand of any chemical technical man.

A Literature Survey of the Thermal Conductivity of Liquids. Byron C. Sakiadis and Jesse Coates. Engineering Experiment Station Bulletin 34. Louisiana State University and Agricultural and Mechanical College, Baton Rouge (1952). 70 pp., \$1.00.

This compilation and evaluation of published methods of measurement of thermal conductivities of liquids and solutions at applicable temperatures is divided into three sections. Section A describes the methods of measurement of various investigators and separates them into two groups, before and after 1923. Section B contains abstracts of the results of the latest research, classified under steady- and unsteady-state heat conduction. Section C contains tables of the thermal conductivities of pure liquids and solutions except liquid metals and helium. There is a bibliography for each section.

### INDIAN CHEMICALS SURVEY

A "SURVEY of the Indian Chemical and Pharmaceutical Industry," sponsored by the Indian Chemical Manufacturers Association, composes the 1951 fall edition of the Chemical Age

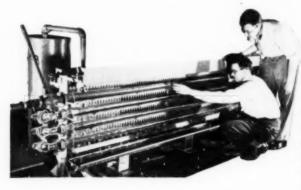
(Continued on page 52)

Acids can't eat away your **PYREX® GLASS processing equipment** 

Dollar for dollar, no other material has the all-around corrosion resistance of Pyrex brand glass No. 7740. Its exceptional mechanical and thermal properties make it ideal for coolers, condensers, fractionating columns, piping and other processing equipment.

What's more, the chemical stability of this PYREX glass provides positive protection against contamination of pharmaceutical and other sensitive products. Transparency permits you to keep an eye on processes-spot defects at a glance. Easy cleaning, another important advantage, results from the hard, smooth surface of glass.

These are only some of the more important reasons why Pyrex brand glass pipe, cascade coolers, fractionating columns and other processing equipment pay for themselves many times over. It will pay you to check with Corning.



# Pyrex™ Cascade Coolers give you two important advantages

The over-all corrosion resistance of Pyrex brand cascade coolers offers you two distinct advantages. First, it prevents chemical attack inside the tubes-thus increasing service life. Second, it permits the use of low-cost river or sea water as a coolant.

Low in first cost per BTU transferred, cascade coolers add further economy because the hard, smooth surface of glass limits scale build-up, reduces fouling.

Highly versatile, they can be mounted on floor, wall, or ceiling to conserve space. Shipped complete, a multitube unit can be quickly assembled by your own men.

For heat transfer nomographs, tables and description of PYREX cascade coolers, send for Bulletin PE-8.

Corning means research in Glass



# Good throughput with Pyrex Columns

You get unusual advantages in solving fractionating and absorption problems with PYREX brand glass fractionating columns. Corrosion resistance assures long service life, low replacement costs. Transparency permits you to observe flow and performance at any stage. Exceptional physical and thermal durability minimize breakage hazards.

Available in 4" and 6" sizes with any number of plates, PYREX fractionating columns have a throughput of 20 to 25 gallons per hour. Gas and liquid samples may be taken at any time without disturbing operation.

Get full information on PYREX fractionating columns and standard packed columns by sending for Data Sheets.

# **Corning Glass Works** Dept. EP-2, Corning, N. Y. Please send me: Bulletin PE-8, PYREX brand Cascade Coolers. Data Sheets for PYREX brand Fractionating and Packed Columns. Title Compony Address City



TANTALUM the acid-proof metal!

Tantalum's speed in heat transfer, freedom from thermal shock, and acid-proof properties add up to equipment that increases production, saves time and space, saves maintenance, saves shutdown time, and eliminates product contamination due to corroded equipment.

Use TANTALUM With Economy for most acid solutions, corrosive gases or vapors; not with HF, alkalis, substances containing free SO<sub>3</sub>.

**Tantolum Steam Coil.** Additional heating capacity obtained by building coil on large steel flange protected by tantalum tube sheet, eliminating risers. Connections are at bottom.

Write for the Fansteel booklet, "Tantalum Acid-Proof Chemical Equipment", and consult Fansteel for designs and recommendations.

TANTALUM
the most nearly
perfect material
of construction

Acid-Proof

TANTALUM

Fansteel Metallurgical Corporation NORTH CHICAGO ILLINOIS U.S.A.

# INDIAN CHEMICALS SURVEY

(Continued from page 50)

series, a publication devoted to the chemical-process industries of India and published semiannually in Bombay.

The semiofficial character of this survey, which was instigated by the National Planning Commission, suggests its reliability. Besides brief data on raw materials, production, price, exports and imports, consumption, and government regulations for such industries as acids, fertilizers, alkalies, pharmaceuticals, coal tar, plastics, dyestuffs, etc., this survey includes a "classified index to chemicals and chemical products made in India" and a descriptive list of members of the Indian Chemical Manufacturers Association. There are few charts or tables, most of the data being incorporated within the text.

# What Do You Know About Polymers?

Fundamental Principles of Polymerization — Rubbers, Plastics, and Fibers. G. F. D'Alelio. John Wiley & Sons, New York (1952). 517 pp., \$10.00.

Reviewed by G. R. Barrett, Res. Dept., Monsanto Chemical Co., Everett, Mass.

The author, well known in the field of polymer chemistry by virtue of his laboratory manual. Experimental Plastics and Synthetic Resins, and by his many patents dealing with polymers, states in the preface that his current volume summarizes what he believes to be the "minimum fundamental knowledge that a scientist in the field of polymers should have."

The introductory chapters deal with the properties characteristic of various types of polymeric materials, then with the classification of polymers and polymerization reactions and finally with the historical development of the modern concept of macromolecules in contrast to earlier theories of association of small molecules through secondary valence

Succeeding chapters deal more in detail with condensation and addition polyreactions, polymerization techniques, various methods of average molecular weight determination, and reaction kinctics. Polymerization in emulsion is discussed in considerable detail. A final chapter deals with the problems of copolymerization of two or more vinyl monomers and concludes with a section on polymer degradation.

The approach as implied in the preface is more to teach general principles than to give a complete review on specific polymers. It is well indexed, and text is supplemented with figures and tables. The profuse documentation is, indeed, fortunate since the book appears to have suffered from inadequate proofreading. Errors in equations, both mathematical and chemical, and inadequate identification of symbols occur frequently enough to make necessary either critical amendment by the skilled polymer chemist or a re-check of the original references for the seriously interested novice. Errors in spelling and grammar are likewise unfortunately frequent.

Chapter II has a section on definitions, including several new terms, such as "segmer" and "comer," which the author is apparently offering for general adoption but which are not currently in general use or recommended in the recent "Report on Nomenclature in the Field of Macromolecules." (J. Poly. Sci., 8, 257, 1952).

The author's use of telomer, referring to the chain transfer agent as used in high concentration to produce very low molecular weight polymers is not the generally accepted one, which, instead, calls the polymer itself the telomer.

In spite of the several faults noted, the book is recommended as an excellent presentation, in a moderate-sized volume, of the chemical and physical science of polymers.

Modern American Engineers. Edna Yost. J. B. Lippincott Co., Philadelphia, Pa. (1952). 182 pp. \$2.50.

THE careers of twelve American engineers who have achieved signal success are highlighted in this work of Miss Yost, who has made scientific and technological fields her forte. It is rather unfortunate for our readers that the author had to omit, "because of space limitations," representative engineers from the fields of chemical, metallurgical engineering, etc.

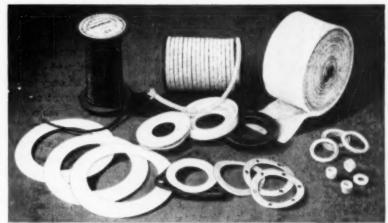
However, some of the studies are not entirely extraneous to the interest of the chemical engineer. For example, the stories of R. E. Doherty and his educational ideal of the development of the whole man, and of Vannevar Bush, director, Office of Scientific Research and Development, whose work "Science the Endless Frontier" attracted considerable attention, have an appeal for all engineers. The other subjects are chosen, not as the greatest in specialized fields but rather as those recognized by their peers as men of high achievement.

An attractive feature of the book and an aid in a quick classification of the man and his field is the plan of the Contents page. Here after the engineer's name are his year of birth (and death), his title and then in a pithy sentence the man's outstanding accomplishment.

These biographical sketches make interesting reading and should be inspirational, too, for the fledgling engineer.

# When it comes to If the PACKINGS and GASKETS

of mechanical packings since 1887



Above - A few of the wide variety of TEFLON packings and gaskets manufactured in the Garlock factories.

GARLOCK pioneered in the design and manufacture of packings and gaskets made of Teflon. Garlock products made of Teflon are unaffected by acids, organic solvents and other chemicals at operating temperatures from below ~90°F, up to 500°F. These packings and gaskets are ideally suited for many other applications due to Teflon's low coefficient of friction.

We have the facilities to mold, machine, or form Teflon in a wide variety of shapes and sizes for packing and gasketing. When you need finished Teflon parts contact your Garlock representative or write for our Teflon Catalog.

> THE GARLOCK PACKING COMPANY PALMYRA, NEW YORK

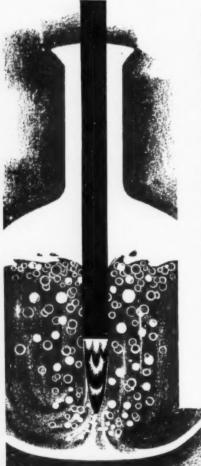
In Canada: The Garlock Packing Company of Canada Ltd., Toronto, Ont.

"The DuPont Company's Trademark

# GARLOCK

PACKINGS, GASKETS, OIL SEALS,
MECHANICAL SEALS,
RUBBER EXPANSION JOINTS

# What does it cost you to heat corrosive liquids?



If you are heating any corrosive liquid—acid, chloride, sulphate or caustic—it will pay you to get the facts about Submerged Combustion, because those facts can save you a lot of money.

High thermal efficiency and negligible replacement costs under corrosive conditions combine to make Submerged Combustion the economical way to heat for processing or evaporation. Heat transfer surfaces can't corrode, can't form scale deposit under any conditions, no matter what liquid you're heating.

Proof? Of course we can prove it — in many cases by reference to an actual installation just like the one you ought to have.

What are you waiting for? Get the facts by writing or wiring at once.

# Submerged Combustion

761 LOGAN STREET

HAMMOND, INDIANA

COMPANY OF AMERICA, INC.

## **NEWS**

(Continued from page 48)

## CHEMICAL ENGINEERING BULLETINS OF T.V.A.

The first of a series of T.V.A. chemical engineering bulletins has been issued recently as Chemical Engineering Bulletin No. 1 titled "The Design of a Phosphate-Smelting Electric Furnace.' by Harry A. Curtis. This bulletin and the succeeding ones will cover subjects of narrower scope than those embraced by the T.V.A. Chemical Engineering Reports. The current bulletin series is intended to supplement the normal outlet for current scientific and technologic data wherever it seems desirable, that is, when a paper that has been prepared is too long or too detailed or of too little general reader interest to be acceptable to the technical journals.

# AMERICAN OIL CHEMISTS SOCIETY MEETS IN MAY

The forty-fourth annual meeting of the American Oil Chemists' Society will be held at the Roosevelt Hotel, New Orleans, La., May 4-6, 1953. The Program Committee is planning papers of diversified interests for the technical sessions. Requests for hotel reservations should be sent directly to the chairman, Hotel Committee, A. F. Freeman, Southern Regional Research Laboratory, 2100 Robert E. Lee Boulevard, New Orleans 19, La.

# AMALGAMATION OF CARBON COMPANIES

Barnebey-Cheney Co, is the new name under which the Barnebey-Cheney Engineering Co, and the American Solvent Recovery Corp. have combined their activities in the activated-carbon, solvent-recovery, and air-purification fields. Headquarters will be in Columbus, Ohio.

The Barnebey-Cheney Engineering Co. has manufactured and supplied activated carbons since 1919. In 1925 the American Solvent Recovery Corp. installed the country's first industrial solvent-recovery plant employing adsorbent carbon.

# OPPORTUNITIES IN PAPER FIELD

"A Career in Paper" is the title of a 31-page booklet published by the National Paper Trade Association, Inc., New York, "in the interest of young people." The booklet presents the views of five successful men in the paper and pulp field who see opportunities and advantages in that industry for young men choosing careers.

(More News on page 59)

# INSTITUTE NEWS

# ANNUAL REPORT OF COUNCIL 1952

This is the annual report of the actions of the Council of the Institute during the period Nov. 1, 1951, to Nov. 1, 1952. During this twelve-month period six meetings of the Council and twelve meetings of the Executive Committee were held. Council meetings were held in the months of December, 1951, January, March, May, July, and September, 1952. The meetings of the Executive Committee were held in each month of the twelve-month period. The practice has been continued of reporting on the meetings of Council and the Executive Committee monthly in Chemical Engineering Progress. Therefore, this report is a summary of the actions taken throughout

#### Membership

The membership of the Institute has continued to show a steady increase. All grades have increased by approximately the same percentages as last year with a net increase in total membership of 9% compared with 9.7% for 1951. Numerically this amounts to substantially the same figure. The Active membership has increased 9.4% in this year as against 8.4% last year. There is a slight reduction in the percentage increase for Associate members this year from 21.3 to but as the numbers were relatively small the numerical increase is about the same. Junior membership has increased only 8.2% this year as against 9.7% last year. Here again the numerical increase is about the same for the two years. Losses in membership are due, in the main, to three causes: resignations, dues delinquency and elections rescinded. Losses due to resignations and dues delinquency amount to only 3.3% of the total membership, which is an extremely low figure compared with the experience of other similar membership organizations. A complete tabulation of the

membership is shown below: Student membership in the Institute, which was initiated in January, 1951, showed a total of 2,303 members in its first year, as reported last year, and as of Oct. 31, 1952, there were 1,726 Student members. The decrease in this grade of membership is explained by the reduction in student en-rollment in the Junior and Senior years and by transfer to Junior membership on the part of some of those who graduated last lune. There is every reason to believe that

this figure will increase in the future, as treshman student enrollments show some improvement this year over previous years.

#### Publications

The official publication of the Institute, Chemical Engineering Progress, has shown very satisfactory improvement in its operations throughout the year. There has been a noticeable increase in nonmember subscriptions and this, coupled with the membership increase in the Institute, has considerably improved the circulation figure. Returns from advertising have been extremely gratifying and have shown steady improvement throughout the year.

Last year's report covered the first announcement of the Institute Lecture Series as a separate publication supplemental to Chemical Engineering Progress. This series of publications as well as the symposium series has been continued. There are now five volumes in the two series available to the membership and several more various stages of preparation which will be available early in the coming year,

The Institute has continued its arrange ment with The Institution of Chemical Engineers (London) in offering to their members Chemical Engineering Progress at a special price and likewise offering their Transactions to Institute members at re-duced prices. The subscriptions to the latter publications have not been as heavy as they might have been, but this is probably explained by the change in the publication procedures of The Institution (London). The last issues of the single-volume publi-cation of the Transactions, The Institution of Chemical Engineers, have been distri-buted to those members of the Institute who indicated a desire to receive them. These are the Transactions covering the year The 1951 Transactions were published in three parts and have been sent to all who subscribed. All members have been advised of the new publication policy of The Institution, but it may be repeated here; the 1952 Transactions are being issued as follows: the first quarterly number in July, 1952, the second in October, 1952 the third in January, 1953, and the fourth in April, 1953. This makes possible the inclusion of all papers presented in, as well as complete reports for, 1952 in the Transactions of that year even though the last two volumes are issued in the succeeding

# Meetings

Four meetings of the Institute were held during the period of this report: the 1951 annual meeting, Atlantic City, N. J., Dec.

2-5; Atlanta, Ga., March 16-19; French Lick, Ind., May 11-14, and Chicago, Ill., Sept. 11-13. The attendance at these meetings has shown a considerable increase over similar meetings in previous years.

The Committee on Constitution and By-Laws completed the task of preparing a set of by-laws which was approved by the Council and published in the 1952 Year Book along with the Constitution.

The Chemical Engineering Education and Accrediting Committee has had an extremely active year, as a large number of curricula were scheduled for review and reinspection and a number of new curricula were inspected. Favorable action was taken on twenty-four curricula in chemical engineering and the curriculum at the University of California in Process Engineering, which was accredited as one in chemical engineering. This action parallels the action taken by the Engineers' Council for Professional Development so that again for 1952 the two lists are in conformity.

Upon recommendation of the Awards Committee the Council approved the granting of the several awards of the Institute at the annual meeting in Atlantic City to the following: the Professional Progress Award in Chemical Engineering to C. G. Kirkbride, Houdry Process Corp., for his many contributions and gifted leadership in Chemical Engineering education and practice, for his scientific developments underlying petroleum technology, and for his tireless and unselfish service to the profession; the William H. Walker Award to R. H. Wilhelm, Princeton University, in recognition of his excellent publication record over the years and his recent contributions to Chemical Engineering Progress; the Junior Award to C. R. Wilke, University of California (Berkeley), for three outstanding papers which have appeared in the publications of the Institute.

The Council changed the title of one of these awards; namely, the Junior Award became the Junior Member Award.

The Student Problem Contest was con tinued again during this year and the usual prizes were awarded as follows:

Karl W. Rausch, Jr., Yale University, The A. McLaren White Award. Kenneth Cantwell, University of Okla-

homa, Second Prize. Preston W. Grounds, Northwestern Technological Institute, Third Prize. Foster W. Rennie, Clarkson College of Technology, Honorable Mention.

Oliver Whipple, Oregon State College, Honorable Mention. Herbert O. Wolf, Polytechnic Institute

of Brooklyn, Honorable Mention. On recommendation of the Student Chap-

ters Committee the time allowed for the solution of the Student Contest Problem was increased from twenty-four days to thirty days in the hope that this would encourage a greater number of students to participate in the contest.

The Scholarship Award program was continued throughout the year, and a cur-rent Junior in nearly every college in the country in which we have a student chapter received the award because of his outstanding scholastic attainments during freshman and sophomore years. The award consists

(Continued on next page)

Membership		.letu:	Associ	ille	Junior		Total
Nov. 1, 1951 Elections Deceased Resigned Dropped Elections Rescinded		474 31 14 23	576 123 2 5 23		6,502 865 1 84 227 23		11,376 1,462 34 103 273 23
Nov. 1, 1952		4,704	669		7,032		12,405
	19.	51	195	52			-1952 rease
Membership	No.	%	No.	%		No.	%
	A 20000						
Active	4,298 576 6,502	37.8 5.1 57.1	4,704 669 7,032	37.9 5.4 56.7		406 93 530	9.4 16.1 8.2

of a certificate, Student membership, a Student member pin, and a two-year subscription to Chemical Engineering Pro-

gress

The Program Committee through a subcommittee established for the specific purpose of judging the quality of presentation of papers at national meetings of the Institute has continued to operate and awards have been given at each of the meetings held during the past year as follows: Atlantic City—David I. Saletan: Atlanta— Parker Frisselle; French Lick—G. J. Maslach; Chicago—Irving Leibson.

#### Student Chapters

A new student chapter at the University of New Hampshire was authorized, thus bringing the number of student chapters to 97.

The Student Chapter News is being continued, and publication is authorized for the school year 1952-1953 with James G. Knudsen, University of Michigan, as editor,

The program established several years ago of Regional Student Chapter Conferences has been continued and eight such conferences were held. As far as possible these were recognized by the Institute through the attendance of an officer or a member of Council. The papers presented by the students at these meetings were judged and cash prizes were awarded as well as subscriptions to Chemical Engineering Progress.

#### Local Sections

Four new local sections were established—one at Terre Haute, Ind., to be known as the Terre Haute Section; another at Atlanta, Ga., to be known as the Atlanta Section; a third at Nashville to be known as Nashville, Tenn., Section, and a fourth at Schenectady to be known as the Northeastern New York Section. Several other areas have groups operating in preparation for the formation of local sections.

#### New Activities

Two new activities of the Institute have been approved by the Council and are in operation. The Research Committee has its program actually under way. Arrangements have been made with three colleges, namely, Polytechnic Institute of Brooklyn, University of Delaware and the University of Michigan, to carry on special research on the subject "Plate Efficiencies in Fractionating Columns." The program is divided into three parts with one assigned to each of the colleges. Progress reports can be expected at about six-month intervals in the future as this program is designed to carry over a five-year period. It has been financed solely by contributions from industry.

dustry.

The Public Relations Committee, working in cooperation with Council, has prepared a questionnaire which, it is hoped, will bring out information of value in establishing policies regarding the Institute, its publications, and also some information regarding the chemical engineering profession in general as to age, economic status

and nature of work.

#### Cooperation with Other Groups

Cooperation with other groups in the engineering field has continued to be an important activity. To mention a few groups with which we have cooperated closely—the Engineering Manpower Commission of Engineers Joint Council, the

Engineers Joint Council, the Engineers' Council for Professional Development, the Pan American Union of Engineering Societies, American Standards Association, National Association of Corrosion Engineers, National Research Council, National Safety Council, and membership has been accepted in the European and United States Engineering Council with the first participation directly in their activity to be expected during the coming year.

The Engineering Manpower Commission

has made considerable progress in encouraging high school students to consider carefully the field of engineering as a life work: it has endeavored to assist industry in the interpretation of the requirements for the deferment from military service of engineering employees. It has also been very active with the Services in an attempt to obtain better utilization of men with engineering and scientific skills, both enlisted personnel and those with reserve status. It is to be expected that as a result of its work legislation will be presented to Congress dealing particularly with the calling and assigning of reservists. This is extremely important as within a few years a very large portion of the younger male population of this country will be in reserve status.

The first meeting of the Pan American Union of Engineering Societies was held in New Orleans in August, 1952, and the Institute was actively represented on committees. G. E. Montes of Baton Rouge was a member of the Local Committee on Arrangements. The next meeting of U.P.A.D.I. is scheduled for São Paulo,

Brazil, in 1954.

Cooperation with the Engineers' Council for Professional Development has continued through membership in all of its committees and especially in the Education Committee through the accrediting activities of both organizations being coordinated.

Cooperation with the American Standards Association has been through membership on several of its committees such as the Chemical Industry Correlating Committee, Safety Code Committee for Mechanical Refrigeration, Standard Code for Pressure Piping Committee, Committee on Letter Symbols and Abbreviations for Science and Engineering, Committee on Graphical Symbols and Abbreviations for Use on Drawings, Committee on Allowable Concentration of Toxic Dusts and Gases, Safety Code Committee for Dry Cleaning Units, and the Committee on Fluid Permeation. The representative on the Standards Council has been E. H. Amick with J. Happel as alternate.

The Council reports with regret the passing during the year of the following members and in so doing expresses a feeling of real loss to the Institute:

Active Members: Harry P. Banks, Raymond I. Bashford, Harry D. Batchelor, W. M. Booth, Fred Charles Bowman, Deane Burns, William S. Calcott, William M. Cobleigh, John B. Ekeley, Gustavus J. Esselen, Robert J. Fletcher, Alvin C. Goetz, Richard P. Horner, Lyle L. Jeune, Wm. Lee Judefind, Bethune G. Klugh, Franklin P. Lasseter, Arthur L. Mohler, Ralph E. Montonna, Irvin Murray, Alexander Newhouse, A. B. Newman, M. H. Norton, W. Ernest Patterson, Clinton R. Powers, David A. Pritchard, Arthur B. Ray, G. Herbert Saniord, Reuben S. Tour, James G. Vail, J. L. Wallace and Richard Taylor.

Associote Members: Samuel C. Dixon and J. C. Lottes.

Junior Members: Junior W. Whitney.

# SECRETARY'S REPORT

S. L. TYLER

The Executive Committee met in the offices of the Institute on the morning of Jan. 16 with all members in attendance. Minutes of previous meeting and Treasurer's reports were received, and bills approved for payment.

The Executive Committee voted to recommend to the Council the election of applicants listed in the December, 1952, issue of "C.E.P." in accordance with the recommendations of the Committee on Admissions.

mittee on Admissions

Student Members numbering 773 were elected to membership.

W. L. McCabe was approved as representative of the Institute at the inauguration of Buell Gordon Gallagher as seventh president of The City College of New York on Feb. 19,

Upon recommendation of the Student Chapters Committee E. W. Merrill was appointed counselor of the student chapter at Massachusetts Institute of Technology to succeed J. N. Addoms.

Five elections to Junior membership and one to Active membership were rescinded because of non-acceptance.

The following members of the Institute were placed on the Suspense List because of their having entered the Armed Services: Richard A. Arnold, Rufus C. Brock, Allen K. Haller, Jacob J. Kaduar, Donald M. Knudson, Carl F. Meyer, Richard Moser, Fred C. Ohnmeiss, Vincent D. Patton, Roger Petersen, Victor R. Struber, Richard F. Sanders.

Resignations were accepted from thirty-nine members in good standing and five memberships were discontinued because of nonpayment of dues.

The Council of the Institute met at The Chemists' Club on the afternoon of Jan. 16, 1953. Following approval of Minutes and the handling of other routine matters, committee personnel appointments for 1953 were completed and the liaison members of Council appointed to represent the various standing committees of the Institute at Council meetings were appointed.

The general program of the Institute for 1953 was discussed at considerable length and an outline of matters to be studied by Council was prepared.

Council accepted the recommendations of the Executive Committee regarding the election of applicants listed in "C.E.P.," in the December, 1952, issue.

The dates of Dec. 12-15, 1954, were approved for the annual meeting to be held at the Statler Hotel, New York.

In accordance with the provisions of the By-Laws, Section IV, paragraph 9, eighty-one members of the Institute were continued as members but excused from the payment of dues.

#### TREASURER'S REPORT

The financial position of the Institute as to cash and investments as of Oct. 31, 1952, and compared with the previous year was:

	1952	
Total bank balances.\$ Negotiable bonds.		
U. S. Savings Bonds.	35,000.00	25,000.00
Conv. pfd. stocks, at	45,140.00	45,140.00
Total cash, bonds	11,300.00	*******

and	stocks	\$ 218,401.11	"	179,934.9
	et value			
stoc	ks	\$ 45,354.69	\$	24,775.0

Since Oct. 31, 1951, the following securities were purchased by the Institute:

	Cost
\$5,000 face value—Pacific Gas and Electric 1st ref. 3's due	
6-1-74	4,900.00
N. J. deb. 234's due 7-15-74 50 Shares—Merck and Co., Inc.,	4,900.00
\$4.00 conv. 2nd pid	5,800.00
4% cum. conv. pfd	5,500.00
Total cost \$	21 100 00

Dec. 2, 1952 C. R. DeLong, Treasurer

## IT'S GRATIFYING

The Membership Committee of A.I.Ch.E. is rather proud of the results of its 1952 drive for new members for the Institute. Against 361 applications submitted by the committee's representatives in 1951, 520 were submitted in 1952. Especially to be noted is the outstanding job performed by the South Texas Membership Committee in obtaining ninety-one applications from that area. The first sixteen in the order of membership applications in 1952, according to J. L. Olsen, chairman of the Membership Committee, are as follows:

	Membership Applications		
Local Section	1952	1951	
South Texas	91	20	
Philadelphia-			
Wilmington	64	65_	
St. Louis	44	33	
New York	36	13	
Chicago	27	17	
New Jersey	22	50	
Batan Rouge	18	13	
Cleveland	17	5	
Southern California	16	10	
Akron	14	13	
Western New York	13	0	
Pittsburgh	13	26	
Louisville	11	3	
Western Massachusetts	11	4	
Maryland	10	10	
Columbia Valley	10	12	

# This NEW METHOD DRIES AIR

# PRECISELY as you want it

- b to control your product's quality
- b to prevent condensation on your product or material
- b to prevent changes due to moist air in contact with your product
- b to protect your material from dampness
- ▶ to protect your processing of moisture-sensitive material
- b to DRY your material or product
- to pack or store your product safe from moisture damage
- to get exact moisture control for the precise atmosphere condition you need
- b to provide precise atmospheric conditions for testing
- b to increase your air conditioning capacity
- ▶ to DRY large quantities of fresh air from outdoors

# The Niagara's Controlled Humidity Method using HYGROL moisture-absorbent liquid is

Best and most effective because ... it removes moisture as a separate function from cooling or heating and so gives a precise result constantly and always. Niagara machines using liquid contact means of drying air have given over 20 years of service.

Most reliable because... the absorbent is continuously reconcentrated automatically. No moisture-sensitive instruments are required to control your conditions.

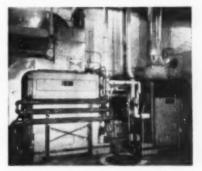
Most flexible because ... you can obtain any condition at will and hold it as long as you wish in either continuous production, testing or storage.

**Easiest to take care of because . . .** the apparatus is simple, parts are accessible, controls are trustworthy.

Most compact, taking less space for installation.

Inexpensive to operate because ... no re-heat is needed to obtain the relative humidity you wish in normal temperature ranges and frequently no refrigeration is used to remove moisture.

The cleanest because . . . no solids, salts or solutions of solids are used and there are no corrosive or reactive substances.



# Niagara Controlled Humidity Air Conditioning

This method removes moisture from air by contact with a liquid in a small spray chamber. The liquid spray contact temperature and the absorbent concentration, factors that are easily and positively controlled, determine exactly the amount of moisture remaining in the leaving air. Heating or cooling is done as a separate function.

For complete information write

# NIAGARA BLOWER COMPANY

Dept. EP, 405 Lexington Ave., New York 17, N. Y.

District Engineers in Principal Cities of United States and Canada

# CANDIDATES FOR MEMBERSHIP IN A. I. Ch. E.

The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee on Admissions.

These names are listed in accordance with Article III,

Section 7, of the Constitution of A.I.Ch.E.

Objections to the election of any of these candidates from Active Members will receive careful consideration if received before March 15, 1953, at the Office of the Secretary, American Institute of Chemical Engineers, 120 East 41st., New York 17, N. Y.

#### **Applicants for Active** Membership

Baker, Harry L., Jr., Atlanta, Ga. Barnett, Martin J., Wilmington, Del.

Brown, Edward C., Montreal, Que., Canada

Caldwell, H. P., Jr., Paulsboro, N. J.

Coulter, K. E., Midland, Mich.

Donovan, John R., Richmond Heights, Mo

Duchacek, Charles F., Sunnyside, N. Y.

Ferrin, Harold E., St. Joseph, Mo. Fitt, T. Cleon, Selby, Calif.

Gaylor, Hunter E., Calvert City, Ky.

Hokanson, Allan E., Brooklyn, N. Y.

Jackson, Frank L., New York, N. Y.

Jones, James B., Jr., Wilmington, Del

Kichline, Thomas P., Reading, Mass.

Kieffer, Lewis M., Hattiesburg, Miss.

Kolodney, Marris, New York, N. Y. Marshall, Edward E., East St. Louis,

Mercier, George T., Jr., Pasadena, Texas

Metzger, G. Herbert, Lorain, Ohio Mitchell, James A., Kingsport, Tenn.

Potter, Chas., New York, N. Y. Ray, Charles A., Jr., Phillips, Tex. Robb, W. Dwight, Bay Village, Ohio

Rose, Arthur, State College, Pa.

Schroeter, Donald G., Texas City,

Smith, Edwin J., Weirton, W. Va. Sperling, C. C., St. Albans, W. Va. Sysko, Adam J., Wilmington, Del. Trainer, Richard P., New York, N. Y.

Trenholme, L. B., Texas City, Tex. Weldele, Richard G., Indianapolis,

Wheelock, George L., Akron, Ohio Wilbur, Paul C., San Jose, Calif.

# **Applicants for Associate** Membership

Hack, Walter, Jr., Glenview, III. McRobert, Leon E., Brooklyn, N. Y. Mellecker, John B., Springdale, Conn

Osborn, Eugene C., St. Louis, Mo. Ting, Andrew P., Philadelphia, Pa.

# **Applicants for Junior** Membership

Acquard, William E., Elsmere, Del. Ahlert, Robert C., Long Island, N. Y.

Allen, Thomas S., Baton Rougs, La. Baetz, Ernest A., Jr., Baytown, Tex. Behn, Eugene, Freeport, Tex.

Bottenfield, Bill D., Chillicothe, Ohio

Bresee, James Collins, Parlin, N. J. Brown, James G., Royal Oak, Mich

Cauley, Jack E., Jr., Baytown, Tex. Claus, Fred R., Joliet, Ill.

Coon, Don J., Jr., Monaca, Pa. Cornman, Richard W., Dundalk, Med

Crone, E., Chicago, III.

Doran, Martin R., Vermilian, Ohio Doremus, John Fred, Carteret, N.

Dunlop, Donald D., Baton Rouge, La.

Eu, Andrew K. W., Secaucus, N. J. Feldman, Rubin, St. Louis, Mo.

Ferry, Neal J., Hazleton, Pa. Fey, Richard S., Cumberland, Md.

Fish, Leonard W., Stamford, Conn. Fisher, Joseph C., Pottstown, Pa.

Flanagan, Joseph F., Springfield, Mass.

Gough, James A., Houston, Tex. Haupt, Donald E., Hauston, Tex.

Hellhake, F. J., Trenton, Mich.

Heyse, Herbert W., Bartlesville, Okla.

Hollembeak. John W., Rock Springs, Wyo.

Ingels, Raymond M., Galveston, Tex.

Jarboe, James A., Texas City, Tex.

Kessler, Marvin M., Roxana, III. Kimble, Harvey S., Bartlesville, Okla

Langlois, Darwin James, Niagara Falls, N. Y.

Leeser, Russell E., Bellevue, Mich. Levin, Donald James, Ft. McClellon. Ala.

Lincoln, Patrick A., Wilmington, Del.

Lynn, R. Emerson, Jr., Akron, Ohio Marion, Charles P., Whittier, Calif. Martin, Charles Andrew, N. Arlington, N. J.

Masters, David E., Worcester, Mass. McMillin, Fred A., El Segundo, Calif

Mikity, E. J., Stamford, Conn.

Miller, George L., Niagara Falls, N. Y.

Muthig, Wesley F., Detroit, Mich. Neugold, Ronald R., Malverne,

Nielsen, John D., Whiting, Ind. Plummer, Dirk A., Ft. McClellan, Ala

Pollack, Ephraim Leo, Branx, N.Y. Prest, James A., Waukegan, III.

Prok, George M., Lakewood, Ohio Rector, James W., Baton Rouge, la.

Rickerson, Raymond M., Deer Park, Tex

Robards, Henry Eugene, Jr., Apartado, Barcelona, Venezuela Robertson, James F., Paramus,

Robinson, Lewis A., Woodbury, N. J.

Rodakis, John M., Flushing, N. Y. Rushford, W. H., Borger, Tex.

Shickel, Philip, Niagara Falls, NY

Shull, Dale B., Rock Springs, Wyo. Sisneros, Tom E., Marion, Ind.

Slawecki, Tadeusz K., Philadelphia, Pa.



# Low Cost Protection

# **HEAT EXCHANGER TUBE ENDS**

In the past 31 years Conseco has provided millions of Flowrites for tube inlets of heat exchangers operating in all industries and all applications. Tube inlets be-come eroded and worn long before the remainder of the tube, and by reinforcing the inlets it is possible to increase the effective tube life many times.

Flowrites-made of the same metal as the tubesare available in any length, diameter or gauge. They are easy to install and remove by unskilled help. When Flowrites themselves become worn (instead of the tubes!), just pull them out and install new, longer Flowrites.

Get the facts from the 8-page Flowrite "proof" booklet, available upon request.

# CONDENSER SERVICE & ENGINEERING CO.

80 RIVER ST., HOBOKEN, N. J.

Slovachek, Robert J., Racine, Wis. Smith, Harold M., LaGrange, III. Snyder, John D., Watervliet, N. Y. Stalder, William L., Bartlesville, Okla. Tarcha, Paul, Wood River, III. Thompson, H. Lytle, Chicago, III. Vasgoard, Julian E., Springfield, Mass. Vagler, William H., University, Ala. Wade, Garnett L., Jr., Decatur, Ala. Walser, Frederick Robert, Drexel Hill, Pa. Weating, Ernest G., Pittsburgh, Pa. Weinberg, Allen B., Chicago, III. Wilder, John W., Kingsport, Tenn. Withers, H. W., Kingsport, Tenn. Woo, Davis, Morgantown, W. Va. Wunderlich, O. A., Crystal Lake, III. Wurth, Thomas J., St. Louis, Mo.

## NEW CLASS FORMING AT OAK RIDGE

The Oak Ridge School of Reactor Technology will accept applications for admission to its fourth session until March 1, 1953. The class will begin in September. Applicants must be recent college graduates or sponsored students from industry or government agencies.

At the third formal class of the school, which began on Sept. 8, 1952, eighty-one students, selected from 250 applicants, reported for the 12-month course in reactor technology at Oak Ridge National Laboratory operated for the Atomic Energy Commission by Union Carbide and Carbon Corporation.

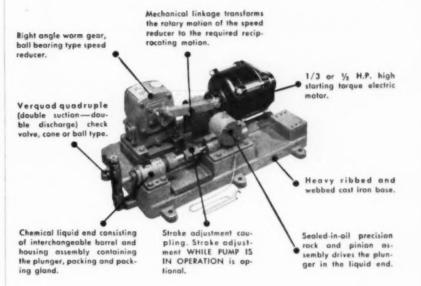
The objective of the school is to provide a source of the uniquely trained technical personnel required for the A.E.C.'s reactor-development program by training selected university graduates, who join various government agencies and atomic energy contractors as regular employees at the end of the training period. The school also supplements the training of practicing engineers and scientists from industry to enable them to participate, through their sponsoring organizations.

#### HEAT TRANSFER SYM-POSIUM AT ST. LOUIS

A full day's session will be devoted to a symposium on Heat Transfer at the 1953 annual meeting of A.I.Ch.E. to be held in St. Louis, Dec. 13-16. R. M. Lawrence of Monsanto Chemical Co. is technical program chairman for this meeting, and Prof. D. L. Katz, University of Michigan, and chairman of the symposium, is currently soliciting papers for presentation. Complete papers must be submitted by Arg. 1 to be considered.

In accordance with a decision of the Program Committee of A.I.Ch.E. preprints will be prepared and will be offered for sale at cost in advance of the meeting.

# Simplicity of design plus precision manufacture



# assure high standards of accuracy and dependability in Hills-McCanna "U" type metering and proportioning pumps

Whenever small volume flows must be metered or proportioned continuously, the simple, foolproof design of Hills-McCanna "U" Type Pumps pays big dividends. For flows up to 24 gallons per hour per feed, its accuracy and reliability suit it for research, pilot plant operation and full scale processing alike.

The "U" type pump is available in a range of capacities with 1, 2, 3 or 4 feeds. Its design permits use of a wide variety of materials of construction in the liquid end.

Write for descriptive literature which gives full information. HILLS-McCANNA CO., 2438 W. Nelson Street, Chicago 18, Ill.

# 'NNLG-MEGANNA'

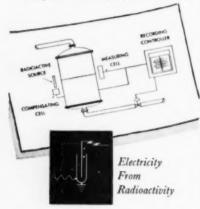
metering and proportioning pumps

Also Manufacturers of:
SAUNDERS TYPE DIAPHRAGM VALVES

FORCE FEED LUBRICATORS . MAGNESIUM SAND ALLOY CASTINGS



New Ohmart Density Gauges "see" into steel vessels-simply and directly perform many "hard-to-do" measurement tasks with amazing accuracy! The penetration power of radioactivity is utilized to make easy many different evaluations of process variables, up to now difficult or impossible because of such conditions as extreme temperatures or pressures, or corrosive or erosive elements. A typical application is shown in the diagram below-where the Ohmart Density Gauge is used for liquid level measurement. Operation is simplestandard electronic instruments are used: equipment is sturdy and easily installed (usually with NO connections into the vessels themselves); only small, safe quantities of radioactivity are required. If you have any difficult process variables evaluation problem, where density is a function of the desired measurement, look to Ohmart Density Gauges for your solution. Write today for information, consultation,



# the ohmart corp.

2339 FERGUSON ROAD CINCINNATI 38, OHIO DALLAS CHICAGO

# TECHNICAL PROGRAM

(Continued from page 32)

9:00 A.M.-"ELECTRO-CHEMICAL PROCESS AP-PLICATIONS FOR ION EXCHANGE MEM-BRANES," by Robert Kunin, Rohm & Haas Company, Philadelphia, Pa.

9:40 A.M.—"MANGANESE RECOVERY FROM LOW GRADE ORES," by Louis N. Allen, Jr., Chemical Construction Corp., New York, N. Y. 10:20 A.M.-"FLUIDIZED-BED SULFATE ROAST-ING OF NONFERROUS METALS," By F. M. Stephens, Jr., Battelle Memorial Institute, Columbus. Ohio.

11:00 A.M.-"RECOVERY OF VANADIUM BY ION EXCHANGE," by R. Long, Dow Chemical Company, Pittsburg, Calif.

#### TECHNICAL SESSION NO. 9

Symposium on Fluid Mechanics

9:00 A.M.-"TRANSFER OF MOMENTUM IN JET OF AIR ISSUING INTO A TUBE," by E. W. Comings, Professor of Chemical Engineering, Purdue University, Lafayette, Ind.

9:30 A.M.-"TRANSPORT OF MOMENTUM AND ENERGY IN A DUCTED JET," by L. G. Alexander, A. Kivnick, E. W. Comings and E. D. Henze, Department of Chemical Engineering, The University of Oklahoma, Norman, Okla.

10:10 A.M.-"PIPELINE DESIGN FOR NON-NEWTONIAN FLUIDS," by A. B. Metzner, Colgate-Palmolive-Peet Company, Jersey City, N. J.

10:40 A.M.-"PRESSURE DROP IN SINGLE-PHASE FLOW THROUGH PACKED COLUMNS," by R. H. Crowther and R. G. Taecker, Department of Chemical Engineering, Kansas State College, Manhattan, Kan.

11:10 A.M.-"CO-CURRENT TURBULENT-TURBU-LENT FLOW OF AIR AND WATER-CLAY SUS-PENSIONS IN HORIZONTAL PIPES," by H. C. Ward and J. M. DallaValle, Department of Chemical Engineering, Georgia Institute of Technology, Atlanta, Ga.

# BILOXI MEETING

(Continued from page 31)

## Side Trip

For those who have some time to spend in the region, the annual Natchez Pilgrimage, held this year from February 28 to March 29, offers an opportunity to visit old Southern mansions and lovely Southern gardens. Natchez is on the way to Biloxi for those driving from the midwest, and for others there is good bus service between New Orleans and Natchez, Information may be obtained from the Natchez Pilgrimage, Natchez.

## Hotels and Transportation

All meetings will be held at the Buena Vista Hotel. Members and their guests will be accommodated at the Buena Vista and the near-by White House hotels on the American plan. Contrary to our earlier report, the European plan is not available. It is suggested that members arrange to share rooms, as most of the rooms are double. Bus transportation between the two hotels will be provided from eight to nine and five to six o'clock

Biloxi is reached from the East by the Louisville and Nashville Railroad. Members from other parts of the country will find it convenient to go directly to New Orleans or Mobile, either city being about an hour-and-a-half trip from Biloxi by the Louisville and Nashville Railroad or the Greyhound Bus Line. Both the Southern and National airlines go to Gulfport, Miss., which is 15 minutes from Biloxi.

#### CAMPAIGN TO EASE ENGINEER SHORTAGE

The answer to the engineering manpower shortage lies partly with teenagers and their parents, according to Chester H. Lang, vice-president of public relations, General Electric Co. Mr. Lang is coordinator of the "Engineers Wanted" campaign of The Advertising Council, which is cooperating with the Engineering Manpower Commission of the Engineers Joint Council in trying to attract more young men to engineer-

One of the reasons for the current shortage of between 35,000 and 45,000 engineers, Mr. Lang said, is the lack of adequate guidance given young people in their first and second years of high school. Engineering colleges require more mathematics and science than a student is likely to take unless he has early decided on engineering as a profession. Many young men, consequently. are unable to enter technical courses even though their interest has been aroused by the time they reach college

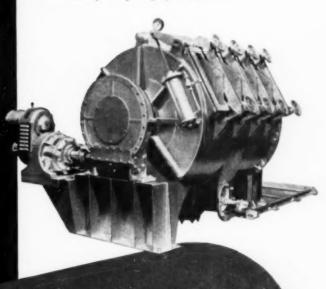
To remedy this and other causes of the engineer shortage, the Engineering Manpower Commission has asked The Advertising Council, a non-profit service organization, to launch a campaign to coordinate the disparate activities of schools, colleges, and industry in attracting a larger number of qualified young

people to the profession.

A booklet. "How Your Company Can Help Promote Engineering as a Career," outlines ideas for company participation in the campaign, which will be intensified at the local, rather than the national, level. It offers sample advertisements, spot radio announcements, and publicity Another booklet, entitled releases. "Engineering as a Career," is addressed to young men and their advisers. This material may be obtained from The Advertising Council, 25 West 45 Street, New York 36, N. Y.

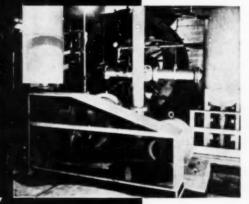
dependable process equipment built to fit your needs

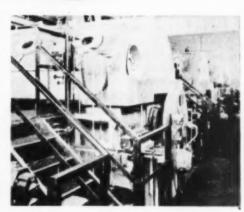
Conkey Rotary Leaf Pressure Filters; a preeminent type for clarification filtration; builds a cake, washes out solubles, dewaters and discharges the cake, all without necessity for opening up of the filter.



CONKEY FILTERS FOR CHEMICAL PLANTS

Conkey Rotary Hopper Vacuum Dewaterers, high capacity top feed vacuum filters for fast filtering and rapidly segregating slurries, require no adjustments for feed variations in consistency and particle size.





**Process Equipment Division** 

Send for latest bulletin on Filters

Conkey Hooded Rotary Drum Vacuum Filters effectively handle filtrations where volatile solvents are a component of the slurry feed or of the wash application.

# GENERAL AMERICAN TRANSPORTATION CORPORATION

Sales Office: 10 East 49th Street, New York 17, New York Denseral Offices: 135 South La Salle Street, Chicago 90, Illinois anode: Canadan Locomotive Company, Ltd., Kingston, Ontario OFFICES IN ALL PRINCIPAL CITIES

Other General American Equipment: Turbo-Mixers • Evaporators • Dewaterers
Towers • Tanks, • Bins • Dryers • Pressure Vessels

# NEWARK "End-Shāk" TESTING SIEVE SHAKER



Here, in the Newark "End-Shāk" unit, you get proper sustained hand motion mechanically. You get the best motion without being subjected to any human variation or weakness. This sturdy testing machine holds up to 7 full height sieves or up to 13 half height sieves. It is designed for 8 inch diameter sieves. Standard ½ HP., 110-220 volt 60 cycle, 1750 rpm motor supplied. Special motor to order.

NEW ARK

We'll be glad to send you prices and descriptive literature. And if you will outline your testing requirements we'll be glad to suggest the proper sieve series to use.

Newark Wire Cloth

351 VERONA AVENUE • NEWARK 4, NEW JERSEY

Philadelphia 3, Penna. San Francisco, Calif. Chicago, III. New Orleans, La. Los Angeles, Calif. Houston, Texas 1311 Widener Bidg. 3100 19th St. 20 M. Wacker Dr. 520 Maritime Bidg. 1400 Sa. Alameda St. P. O. Bea 1970

# ZIRCONIUM PLANT FOR CARBORUNDUM METALS

A \$2,500,000 plant to produce zirconium and hafnium metals is being designed by the Rust Process Design Company. Pittsburgh, for the Carborundum Metals Company, Inc., at Akron, New York.

The latter company, a new subsidiary of Carborundum Company, recently signed a five-year contract with the Atomic Energy Commission for delivery of 150,000 pounds of zirconium and hafnium sponge metals from the new facility each year.

Zirconium and hafnium, an impurity of zirconium, are used in nuclear reactors. Raw material will be zircon sands obtained from the beaches of Florida and southern inland areas where the

sands are strip mined.

In the initial steps of zirconium processing, the zircon sands are first heat treated in an electric furnace to make carbide. This phase will be handled by the parent Carborundum Company in existing facilities. The processing of the carbide will be carried out in the new Carborundum Metals plant first to a chloride, then through purification of the zirconium chloride and final reduction of the zirconium and hafnium to sponge metal for shipment to the A.E.C.

The present plants at Oak Ridge and Albany, Ore., are basically experimental, and the A.E.C. has been sponsoring research to develop production of the metals by a commercial operation.

Rust Process Design Company is currently cooperating in a research project being carried on at the Mellon Institute. Pittsburgh, under a Carborundum Company fellowship to develop improvements in the process of producing the zirconium and hafnium metal sponge from the zircon ore.

The reduction process, a modification of the Kroll Process, is basically that developed at the Bureau of Mines station at Albany, Ore., where Dr. William Kroll was for many years a consultant.

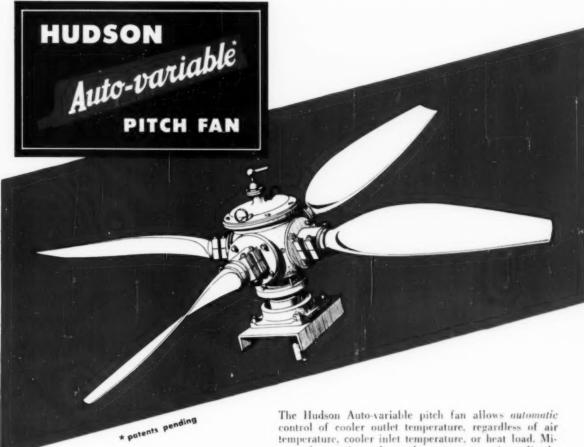
Construction of the new plant is underway. Plans call for a July, 1953, start-up of the new facility, according to a Rust official.

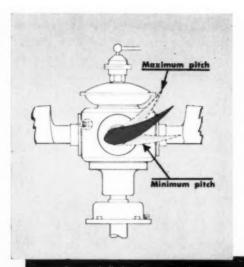
#### A.M.&M. BUYS NIAGARA FILTER CORP.

Officials of American Machine and Metals, Inc., and of Niagara Filter Corporation, announced last month that American Machine and Metals has acquired the business and certain assets of Niagara Filter Corporation, manufacturers of closed pressure-type alluvial leaf filters for the chemical and processing industries. Henceforth, the filter business will operate as a division of American Machine and Metals, Inc., retaining the Niagara name.

(More News on page 65)

# Another NEW DEVELOPMENT by HUDSON





for pitch limit adjustment shown from maximum to minimum.

The Hudson Auto-variable pitch fan allows automatic control of cooler outlet temperature, regardless of air temperature, cooler inlet temperature, or heat load. Minute changes in cooler outlet temperatures immediately and automatically change pitch of fan blades increasing or decreasing the air flow across the coolers. This device marks an important advance in use of air for cooling—saving power, eliminating shutters, and smoothing process operations. Auto-variable fans will find wide application in cooling of jacket water and condensing hydrocarbon vapors and steam.

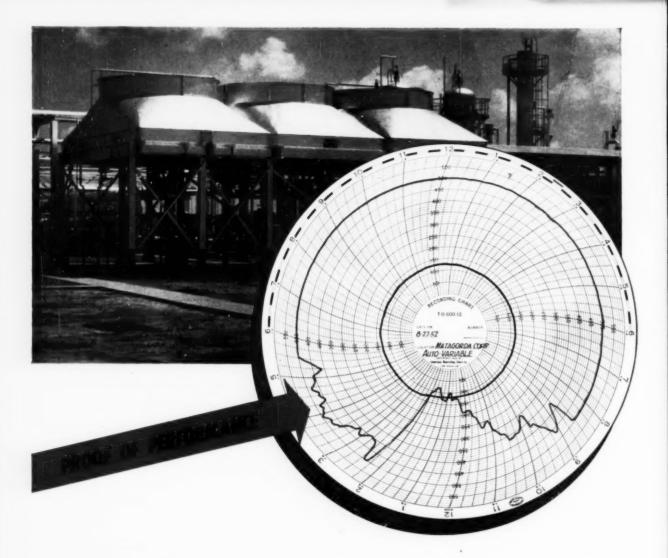
# The HUDSON Auto-variable pitch fan . . .

- · Controls temperature.
- · Saves power.
- Reduces cost of control equipment.
- Prevents freezing due to cold weather.
- Eliminates by-pass piping.
- Operates with standard pneumatic instruments on 0-15# air pressure.

Hudson Auto-variable fans are available in sizes from 6 to 18 foot diameter for use in Hudson Solo-aire air cooled units and in Hudson Combin-aire units.

PROOF OF PERFORMANCE





70 PERCENT SAVING IM

During the 24 hour period the measured electric power consumption was 30% of that which would have been required had the blade pitch been at a constant maximum. Shown above is a facsimile of a chart taken from a recording instrument used in controlling temperature on a Solo-aire gasoline condenser installed in Matagorda Corporation plant near Bay City, Texas. The outer line (red) shows the fan pitch variation required to maintain constant stream temperature (black line).

Despite air temperature variation from 72°F to 100°F, and despite changes in the heat load, the outlet temperature from the cooler was held constant throughout the 24 hour period.





# THOMAS DECRIES MORATORIUM ON SCIENCE

Charles Allen Thomas, president of Monsanto Chemical Co., speculated on the catastrophe of a moratorium on scientific progress in a speech last month in acceptance of the Perkin Medal, highest award for achievement in American industrial chemistry.

Dr. Thomas received the award for his outstanding contributions to the chemical technology of automotive fuels. of catalysts, of synthesis of valuable products from petroleum, and of atomic energy. Founded in 1906, in honor of Sir William Henry Perkin, who discovered the first synthetic dye, the medal is awarded annually by the American section of the Society of Chemical Industry with the cooperation of other American chemical groups.

In his speech Dr. Thomas answered the question what would happen with a fifty-year world moratorium on science? In medicine, he said, there would be no hope for a cure to the common cold, to polio, to mental illness, to cancer, and "our present drugs would gradually become less effective since germs have a way of building a tolerance for medicines, and in time we would have outbreaks of sicknesses which now we have pretty well under control." There would also be a decline in the number of doctors, he said, for "without the spur of research many lose interest in going into the medical profession."

With a moratorium on science, "how," he asked, "would we compete with hordes of insects that would appear to ravage our crops?" In fifty years insects could completely curtail farm production, since insects develop an immunity to particular chemicals, and presently known pesticides and insecticides would gradually lose their force.

Furthermore, Thomas said, with the present rate of crop production we will have to find an additional two or three hundred million acres of crop land by the year 2000. The only hope of obtaining this is to improve the productivity of land through the application of science. "New types of fertilizers, new types of farm machinery and development of the new concept in agriculture of soil conditioners is the only tool we will have to feed our increased population at the present dietary standards."

In wartime and peacetime alike, Dr. Thomas emphasized, a moratorium on science would obliterate today's civilization, "and thus man's slow climb and his fight against poverty, against disease and for everything which lifts him above the animal, would be precipitately



The New COOPER HEWITT Black Light Unit in the 3660 Angstrom Range

Here is a valuable tool for fluorescence analysis and examination of raw and processed materials in manufacturing, processing industries, and industrial research laboratories. New, modern Corning filter transmits only the bands in the 3660 angstrom region.

A quartz high pressure mercury arc tube in a sealed beam furnishes the desired wave length.

Supplied for flood or spot focus Free-swinging swivel arm permits adjustment of lamp in all positions.

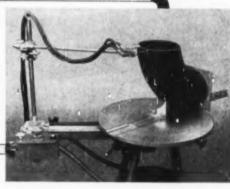
Write for full details today.

# COOPER HEWITT ELECTRIC CO.

730 GRAND ST., HOBOKEN, N. J.

# HERE'S HOW TO WELDING FITTINGS





# VERNON

# Universal" FLAME (CUTTER

Use this new precision "Universal" Flame Cutter for re-working, reconditioning and salvaging all types of new and used welding ells, tees, flanges, reducers, etc. Makes extremely clean cuts . . . no cleaning or hand fitting required. Adjustable degree plate permits fitting to be cut at any angle. Has unitized control panel and unitized gas con-

6" 45" elbow, showing use of the adjustable degree plate.



VERNON TOOL CO., LTD.

1111 Meridian Ave. Albambra, Calif.

P.O. Box 7555 Houston 7, Texas

WHAT IT DOES

- Shortens ells, tees, flanges, reducers, etc. Miters walding neck flanges. Re-cuts and bevels used ells, tees, swedges,
- turns. conditions welding neck and slip-on

- flanges.
  Reams extra heavy fittings to standard.
  Cuts small miters . . . 22½° or less.
  Cuts holes in blanks for slip-on reducing flanges.
- flanges. Cuts and bevels shart pieces of pipe to 36" diameter.
- 36" diameter. Makes swedges out of welding caps. Cuts miter elbows.

Vernon PIPE CUTTING PANTOGRAPH Vernon "Universal" FLAME CUTTER Brown STEEL VALVES .

Vernon-Ormeco TUBE EXPANDING MACHINE



FOR STANDARD
HIGH-PRESSURE EQUIPMENT
WRITE FOR
CATALOG 406-E



For further information on these and other special types of reaction vessels,



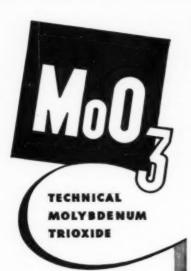
thrown back, and we might find that in a scant fifty-year period, we would be thrown back to an existence not too far removed from the Dark Ages."

Without the incentive to change which is the greatest impetus driving the consumer to trade capital for goods, the entire economy could be wrecked, for without scientific progress there would be no new developments in household appliances, cars, and other consumer durable goods. The terrific resulting unemployment problem, according to Dr. Thomas, could result in a violent revolution which could drive this country into a completely totalitarian state.

Similarly, weapon development would stop, and eventually all nations would have the same weapons. The nation with the largest manpower would then rule the world, since, said Dr. Thomas. "the only method of keeping superior manpower in check is a superior weapon."

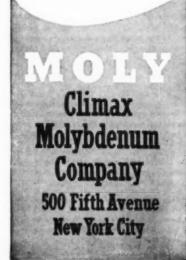
With a science moratorium, therefore, Dr. Thomas continued, "there can be no fight for survival, no war against retrogression." He pointed out that in this country the fight is carried on now by only about two-tenths of one per cent of the population-the three to four hundred thousand persons now engaged in research activities for universities, industry, and the government. About three billion dollars is annually being spent in this country for research, but Dr. Thomas warned, "It concerns me that we think that we can buy research with money alone. This is dangerous thinking. The danger is that the money we are spending in research in the fond belief that that is all we have to do, may not be well spent at all. Spending money doesn't automatically mean good research. In the research laboratory, it's thinking that counts."

Returning to his fantasy of a moratorium on science, Dr. Thomas concluded, "Along with any vanishing science, the spirit of scientific inquiry would vanish, the discipline of science. the meaning of the controlled experiment and the search to uncover the truths of nature would stop. . . . It behooves everyone of us to understand that science must have an environment in which freedom of thought is given full play. On the other hand, let's not smother it like an overindulgent parent with too much money. Let us see to it that we keep it rugged and virile by constructive criticism, because freedom of thought coupled with constructive criticism is vitally essential to have our scientific thought flourish in the future period."



The lowest cost raw material for the production of all Molybdenum compounds, including Molybdenum Orange, Molybdenum Vermilion. and Molybdated pigment colors.

Our development department will gladly take up with you any problems involving the application of Molvbdenum.



## HAZARD FROM INDUSTRIAL CHROMIUM

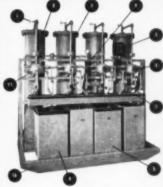
Exposure to chromium compounds used in industry may cause injury to the liver, according to a recent article in the Journal of the American Medical Association (149, No. 15, 1385) by Dr. Luke R. Pascale, Sheldon S. Waldstein, Gertrude Engbring. Alvin Dubin, and Paul B. Szanto. Danger of skin and mucous-membrane lesions and kidney disorders arising from chromium compounds has long been recognized, but only recently has the possibility of further systemic injury been considered.

Dr. Pascale and his associates, examining for jaundice a patient employed in a chromium-plating factory, noted traces of chromium in the body and discovered, after hepatic tests and a liver biopsy, definite liver infection, probably traceable to exposure to toxic chromium compounds. Eight other persons employed in the chromium-plating factory for from one to five years were consequently examined for traces of liver injury, and four cases were found, ranging from mild to moderate. As these patients had as yet exhibited no external symptoms of the disease, there is reason to believe that widespread liver disorder may exist undetected among persons working with chromium compounds

In view of this possibility, caution is enjoined on persons connected with printing, tanning, photography, dveing, electroplating, shipbuilding, aircraft construction, and other industries using chromium. The authors advise, "If it he true that industrial exposure to the toxic chromium compounds may cause systemic as well as surface injury in the human, the health hazard in plants using these compounds is not as negligible as suggested in the [medical] literature. Prophylactic measures, such as adequate ventilation and protective covering, should be taken in all factories to reduce exposure to a minimum. Skin and mucous membrane lesions should be treated promptly to prevent chronic systemic absorption of these compounds."

The most toxic chromium compounds they further describe as follows: "Because of their protein-precipitating and oxidizing properties, chromium trioxide. chromates, and bichromates are potent protoplasmic poisons. Chromic oxide, trivalent chromium salts, and metallic chromium are much less toxic. The maximum safe concentration of chromium trioxide has been considered to be 0.1 mg./cu.m. of inhaled air. Unless proper ventilation is present, the mist from chromium acid baths may lead to concentration of chromium trioxide of 2.5 to 6.5 mg./cu.m. of air.'





- Convenient Air Vent and Sampling
- Uscolite Piping with Flanged Joints Steel Columns Lined with Sheet Rub-ber. Linings 1/2" thick. Vulcanized in Place. (Not Sprayed or Coated)
- Flow Rate Indicator
- Purity Indicating Meter Instrument
- Multiport Valves Lined with Baked Resin. No Metallic Contact
- Water Flow May Be Observed in Trough During Regeneration Self-contained Regenerant Tanks. An Individual Tank for Each Column. Bolted in Place. Easy to Remove
- Acid Tanks Lined with 18 Coats of Acid-proof Duroprene
- Entire "Packaged" Unit on Steel Skid. Easy to Install
- II. Stainless Steel Regenerant Solution Eductors

Barnstead Water Demineralizers are engineered to give you long, trouble-free service . . . they are scientifically designed to produce Pure Water - and water of standardized, controlled quality for as low as 5c per 1000 gallons.

FIRST IN PURE WATER SINCE 1878



BARNSTEAD STILL & STERILIZER CO. 82 Lanesville Terrace, Forest Hills, Boston 31, Mass.

Gentlemen: Please, send me the complete Pure Water story on Barnstead Deminer-alizers.

Name





# INFORMATION 5. L. TYLER, Secretary American Institute of Chemical Engineers 120 E. 41st St. New York 17, New York Dear Sir: Please send me information regarding membership requirements. 2 53 Name: Age:

A.I.Ch.E. MEMBERSHIP

# LOCAL SECTION

EDITOR'S NOTE

True to our promise of last month we are continuing here our account of local section activities—listing new officers where they are known, quoting after-dinner speakers, pointing up a coming symposium, noting the start of a lecture series, and extending greetings to an A.I.Ch.E. section which is currently celebrating its tenth birthday. There are still certain sections which remain noncommunicative, never a line of type about their activities, but we are anticipating some news from them in time for the next issue.

The Maryland Section has invited the student members of the University of Maryland and of Johns-Hopkins University as dinner guests at its meetings in February and March, respectively. At the Deutsches-Haus on Dec. 16, the following officers were elected: L. J. Trostel, chairman; E. L. Knoedler, Jr., vice-chairman, and L. C. Palmer, secretary-treasurer. R. L. Copson and B. T. Dean were elected to the Executive Committee as active member and associaa member, respectively. L. C. Palmer reports that W. T. Nichols, 1953 President of A.I.Ch.E., has been invited to speak before this Section.

From the Ohio Valley Section comes the interesting news that the Section will be host at a symposium in Cincinnati, Ohio, April 24, 1953. Co-sponsors of the meeting are the Akron, Cleveland, and Columbus, Ohio, and the Pittsburgh, Pa., Sections. E. C. Pattee, reporting, says that the subject matter of the papers will be limited to the more recent processes, products and economics of the oil and fat industry, which is one of the processing industries of the Cincinnati area. On Jan. 21 this Section held a joint dinner meeting as the guest of the Ohio Valley Section of the American Society for Quality Control.

#### 10 YEARS OLD

To the Baton Rouge Section we extend congratulations, good wishes, and the best of everything in the year ahead. They were hectic, wartime days when this Section came into being, but despite the times (they are always with us), and imbued with the idea of serving chemical engineers in the area, the Section went forward and during its existence has held sixty-five meetings with an average attendance (excluding joint meetings with other societies) of forty-eight at each meeting. One joint meeting with the A.C.S., immediately following the war, drew about 700 who listened to the thoughts of Dr. Urey of atomic energy fame. We agree with our informer R. H. Bretz that Baton Rouge is justly proud of its record, and climaxing that record by being a co-sponsor of the forthcoming Bilaxi meeting. More about Baton Rouge elsewhere in these pages.

Zone:

State

Theodore Weaver, who discussed formally the Wulff Process in the development of acetylene production in Chemical Engineering Progress (see January issue), was scheduled to discuss the same subject on Feb. 17, at Carolina Pines Restaurant, Los Angeles, before the Sauthern California Section, according to a report by S. G. Sevougian. A former reporter G. S. Peterson has sent this office the names of the new officers of that Section. They are: George R. Lake, chairman; Arnold M. Ames, vice-chairman; S. G. Sevougian, secretary; Blaine B. Kuist, treasurer; B. W. Neumaier, Executive Council (Sr. Member), and John C. Harper (Jr. member).

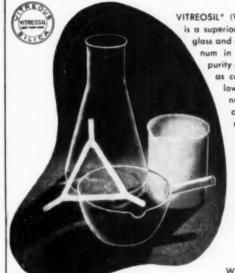
Important Note: All members of A.I.Ch.E. attending the national A.C.S. meeting in Los Angeles during week beginning March 15, are invited to attend the dinner meeting of the Southern California Section of A.I.Ch.E. to be held an Tuesday, March 17, 6:30 p.m., at Mike Lymans Restaurant in downtown Los Angeles. The speaker will be Dr. W. E. Hanford, vice-president of the M. W. Kellogg Co., and his subject will cover the reactions of organic gases under pressure. The speaker is an authority in this field which is af interest to most chemical engineers. Here's your chance, says Reporter Sevougian, to renew your friendships with local members.

To promote the cause of engineering. the District of Columbia Council of Engineering and Architectural Societies has undertaken a campaign to interest high school and preparatory school students in taking courses that will enable them to enter engineering schools. In furtherance of this cause, W. T. Read, chairman of the National Capital Section, has sent a message to A.I.Ch.E. members of that Section soliciting a one dollar bill from each for support of this project. Mr. Read, who has been serving as chairman of the D. C. Council's Education Committee, reports that approximately eighty engineers have already volunteered for service and states that, though no one is being paid for his services, there are inevitable expenses of postage, printing, and the purchase of guidance material. Apparently, it's up to this A.I.Ch.E. section to set an example, since it was "honored by my selection as chairman of the Education Committee." says Mr. Read.

In a departure from the usual evening meetings, says R. W. Sheets, the Detroit Section presented a symposium on "Properties, Performance and Commercial Applications of Silicones" at a luncheon meeting Jan. 9. The Rackham Memorial Building was the scene of this mid-day meeting which was received with enthusiasm by some sixty members and guests. In a series of demonstrations, talks and films the story of silicones was unfolded by four representatives of the Dow Corning Corp., Midland, Mich.

Beginning the program, Don Francisco gave the background and chemistry of silicones. He traced the development of this unusual siliconoxygen chain compound and pointed out its out-

# FOR EXACTING LABORATORY USE



VITREOSIL\* (Vitreous Silica) laboratory ware is a superior replacement for porcelain and glass and a satisfactory substitute for platinum in many cases. Greater chemical purity and high resistance to heat shock as compared to other ceramics and low initial cost compared to platinum have led to the universal adoption of VITREOSIL as a substitute for platinum, porcelain and

adoption of VITREOSIL as substitute for platinum, porcelain and other materials in many analytical procedures.

Standard items of VITREOSIL Laboratory Ware include transparent, glazed and unglazed crucibles, evaporating dishes, beakers, tubing, etc.

Large stock enables prompt shipment.

Write for Technical Bulletins giving full descriptions, specifications, and prices.

# THE THERMAL SYNDICATE, LTD.

14 BIXLEY HEATH

LYNBROOK, N. Y.

MANUFACTURERS OF PROCESSING MACHINES, SINCE 1885

# FOR PRELIMINARY REDUCTION OF SHEET AND FILM FED STOCK

48 inch wide Feed

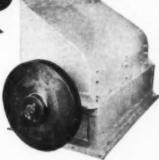


GRUENDLER

Model 3-48
STAINLESS STEEL
SHREDDERGRINDER

Also for handling paper, pulplap, wall board and plastic film sheets.

Other Gruendler Grinders and Shredders available up to 72 inches wide, with or without FEEDERS.



GRUENDLER CRUSHER & PULVERIZER CO.

2915 North Market St.

Dept. C.E.P.

St. Louis 6, Mo.





When you consider the many advantages of Sperry Filter Presses, you can quickly understand why hundreds of manufacturers throughout the country depend on Sperry for solving industrial filtration problems of every kind.

Sperry Filter Presses offer greater economy — low first cost, minimum maintenance and long life . . . require less floor space . . . handle any kind of filterable mixture . . . and use practically any kind of filter material.

For the complete story, ask for the big free Sperry catalog.

D. R. SPERRY & CO. BATAVIA, ILLINOIS

Filtration Engineers for More Than 60 Years

Eastern Sales Representative: orge 5. Tarbox, 808 Nepperhan Avenue, B. onkers 3, N. Y. Yonkers 5-8400 Sai

Western Sales Representative: B. M. Pilhashy, 833 Merchants Exchang San Francisco 4, California DO 2-037: standing properties, such as heat stability, water repellance, etc.

Maurice Hommel then enumerated the many applications of silicones to oils, greases and fluids.

Next, Gordon McIntyre discussed the wide usage of silicones as an electric insulator.

Drawing on his wide experience in the rubber and silicone industries, William Wiard concluded the speeches with a description of silicone rubber applications.

More programs of this nature are being considered.

Prof. J. Joffe, department of chemical engineering, Newark College of Engineering, Newark, N. J., has sent us the prospectus of the forthcoming lecture series in Applied Thermodynamics and Kinetics. Dates and other pertinent information are given here for members of the New Jersey Section and others interested.

March 24—J. B. Maxwell, chemical engineer, Standard Oil Dev. Co.

Topic: Thermodynamic Properties of Fluids

March 31-J. B. Maxwell

Topic: Prediction of Thermodynamic and Other Fluid Properties

April 7—E. C. Schmachtenberg, chief engineer, centrifugal engineering div., Worthington Corp.

Topic: Practical Aspects of Compres-

April 21-J. Joffe, professor, chemical engineering, Newark College of Engineering Topic: Vapor-Liquid Equilibria

April 28—C. Potter, asst. professor, chemical engineering, Columbia University Topic: Reaction Equilibria and Kinetics

May 5—C. Potter

Topic: Applied Kinetics

TIME: 8 p.m.-10 p.m.

PLACE: Clinton School, Clinton Ave. and West 4th St., Plainfield, N. J.

FEE: Individual lecture—\$2; set of six lectures—\$6 for members, N. J. Section, A.I.Ch.E.; \$8 for others.

RESERVATIONS: Send your check to: Joseph D. Stett, Dept. Mech. Eng., Rutgers University, New Brunswick, N. J.

Fred G. Fender, professor of mathematics, Rutgers University, New Brunswick, N. J., addressed the New Jersey Section on Feb. 10 at the Calco Auditorium in Bound Brook, N. J. He told all about the electronic calculator as a scientific instrument. Dr. Fender, from 1946 to present, has been teaching courses in the theory of computing machinery at Rutgers.

It's many a month since this editor has heard from the Baton Rouge Section, but elsewhere in these pages is big news about it. Concerning the elections, the new officers are as follows: R. W. Krebs, chairman; L. H. Stephens, vice-chairman; J. M. Gill, secretary; K. A. Rees, treasurer, and H. C. Henry, J. C. Fedoruk, B. S.



Just a flick of a switch, then read the Brookfield dial, and you have your viscosity determination in centipoises. The whole operation, including cleaning up, takes only a minute or two.

Available in a variety of models suitable for extremely accurate work with both Newtonian and non-Newtonian materials, Brookfield Viscometers are portable and plug in any A.C. outlet. Write today.

Address: Dept. H, Stoughton, Mass.

BROOKFIELD ENGINEERING LABORATORIES. INC



REDUCE INSTALLATION COSTS1 Entire assembly ready to attach to crane or hoist. Only a cable connection is run from Baldwin Load Cell to REMOTE RECORDER.

REDUCE OPERATING COSTSI Great savings in time and man power possible because weighing and transporting operations are combined. Easily removed from crane.

REDUCE MAINTENANCE COSTS: Sturdy load cell can be easily replaced or interchanged.

STREETER-AMET COMPANY

Pressburg, and J. E. Moise, executive committee. At a late meeting in 1952 Wheeler G. Lovell, director of research on automotive products at the Ethyl research laboratory in Detroit, Mich., talked on the basic combustion studies carried out in the Ethyl automotive laboratories to provide a better understanding of the mechanisms and variables controlling combustion of gasolines in engines and the research efforts directed toward eliminating the problems encountered in modern engines. R. H. Bretz reported an attendance of forty-two members and guests.

Tulsa Section held a joint meeting with the Oklahoma Section on Jan. 22 at the Y.W.C.A. in Bartlesville. H. A. Bradley, president, International Chemical Workers Union, Akron, Ohio, discussed labor in the chemical industry. Ray J. Stanclift, Jr., secretary-treasurer of Tulsa Section, reports that Mr. Bradley has been a member of the American Federation of Labor since 1913 and has filled every local union elective post.

As usual the Boston Section Ichthyologists have been busy but practically no news from them has reached this office. Just recently, however, A. G. Smith told us of two interesting meetings held at the M.I.T. Faculty Club in Cambridge. At the first, Dr. T. H. Pigford, professor of nuclear energy at M.I.T. and formerly director of the M.I.T. Engineering Practice School at Oak Ridge, presented the engineer's point of view of atomic energy in a talk titled "An Engineer Looks at Nuclear Energy." At the second, William J. Docey, market analyst with Preston Moss and Co., investment engineers of Boston, attracted his listeners with an address on "How To Get Rich in the Stock Market." (Editor's note: How?) It covered the history, procedures and characteristics of investment practices.

John C. Katz has sent this office the names of the following officers of the Nashville Section. They are: H. J. Kimbrough, Chairman; J. C. Katz, vice-chairman; R. A. Nance, secretary-treasurer; N. A. Copeland, director (two years), and J. C. Barnett, director (one year). Nance informs us that the Jan. 28 meeting featured a talk about the stock market and brokerage, and there was a short movie called "Fair Exchange."

Bernard H. Rosen, publicity chairman of the New York Section, wants members in the New York City area to attend the luncheon meeting on Feb. 17 when Elwood Moffett, assistant to chairman of the organizing Committee of District 50, will talk on District 50, (C.I.O.) and the chemical industry. The meeting will take place at the Brass Rail, Seventh Avenue, New York. F. M. Pyzel of the Foster Wheeler Co. discussed the synthesis of ammonia before the New York Section on Jan. 21. The speaker discussed the present commercial processes for ammonia manufacture pointing out the differences in operating conditions and equipment for these processes.

(More Local Section on page 73)

# CLEAN SEPARATION – between vapor and liquid



# YORKMESH Demisters

are installed in:

VACUUM TOWERS
DISTILLATION EQUIPMENT
GAS ABSORBERS
SCRUBBERS
SEPARATORS
EVAPORATORS
KNOCK-OUT DRUMS, ETC.

YORKMESH Demisters (entrainment separators—mist eliminators) have proved to be the answer to higher production and improved products when installed in new or existing equipment.

YORKMESH Demisters (made of finely woven wire) remove substantially all liquid entrainment even at increased vapor velocities. The net result: More production with higher quality.

# How YORKMESH Demisters work:

 Vapor disengaging from liquid creates fine liquid dreplets.

2. The liquid droplets impinge and coalesce into large draps and fall off.

3. The vapor is new dry, entirely freed from entrained liquid.



Noterials: Types 438, 304, 316 Steinless Steel, Monel, Carbon Steel, etc. Prompt shipment.

Write for new Catalog 13 for camplete information and engineering data.

OTTO H. YORK
CO., INC.

73 Glenwood Place, E. Orange, N. J.

# **DESIGN AND** CONSTRUCTION

means sustained performance, rugged construction and an eye to operational accessibility for maintenance and repairs. We build well our record of repeat orders from satisfied clients attests to that.

## FOR THE CHEMICAL PROCESS INDUSTRY, WE OFFER OUR . . .

Solvent Recovery Equipment \* Extraction Coils \* Evaporators \* Reaction Vessels \* Condensers (for any Vapor) \* Solution Heaters & Coolers \* Exhaust Waste Heat Boilers \* Quenching Oil Coolers \* Storage Tank Heaters \* Gas Coolers \*

Self-Cleaning Heat Exchangers Fractionating Equipment



YOUR PILOT PLANT OR SPECIAL EQUIPMENT requirements can be handled by our experienced staff of chemical and mechanical engineers. We solicit your inquiries.

# DAVIS ENGINEERING

CORPORATION

1058 EAST GRAND ST. ELIZABETH N 30 ROCKEFELLER PLAZA N Y 20, N Y

# FUTURE MEETINGS AND SYMPOSIA OF A.I.Ch.E.

Chairman of the A.I.Ch.E. Program Committee

Loren P. Scoville, Jefferson Chemical Co., 260 Madison Ave., New York 16, N. Y.

#### **MEETINGS**

Biloxi, Miss., Buena Vista Hotel, Mar. 8-11, 1953.

Toronto, Canada, Royal-York Hotel, April 26-29, 1953.

Technical Program Chairman: Brymer Williams, Dept. of Chem. and Met. Eng., University of Michi-gan, Ann Arbor, Mich.

San Francisco, Calif., Fairmont and Mark Hopkins Hotels, Sept. 13-16,

Technical Program Chairman: R. W. Moulton, Head, Dept. of Chem. Eng., University of Washington, Seattle, Wash.

Annual-St. Louis, Mo., Hotel Jefferson, Dec. 13-16, 1953.

Technical Program Chairman: R. M. Lawrence, Monsanto Chem. Co., St. Louis 4, Mo.

Washington, D. C., Statler Hotel, March 8-10, 1954.

Springfield, Mass., May 1954.

Ann Arbor, Mich., Univ. of Mich., Ann Arbor, Mich. June 20-23, 1954—Conference on Nuclear Engineering

Technical Program Chairman: D. L. Katz, Chairman, Dept. of Chem. and Met. Eng., Univ. of Mich., 2028 E. Eng. Bldg., Ann Arbor, Mich

Glenwood Springs, Colo., Hotel Colorado, Sept. 12-16, 1954.
 Annual—New York, N. Y., Statler Hotel, Dec. 12-15, 1954.

Technical Program Chairman: G. T. Skaperdas, Assoc. Dir., Chem. Eng. Dept., M. W. Kellogg Co., 225 Broadway, N. Y. 7, N. Y. Asst. Chairman: N. Morash, Titanium Div., National Lead Co., P. O. Box 58. South Amboy, N. J.

#### SYMPOSIA

Chemical Engineering in Hydrometallurgy

Meeting-Biloxi, Miss.

Fluid Mechanics

Meeting-Biloxi, Miss.

Mineral Engineering Techniques for Chemical Engineers

Meeting-Biloxi, Miss.

Ion Exchange and Adsorption

Chairman: N. R. Amundson, Dept. of Chem. Eng., Univ. of Minnesota, Minneapolis 14, Minn. Meeting-San Francisco, Calif.

Chairman: J. H. Rushton, Dept. of Chem. Eng., Illinois Inst. of Tech., Chicago, Ill.

Meeting-San Francisco, Calif.

Transport Properties Chairman: J. L. Franklin, Res. Assoc., Humble Oil & Refining Company, Baytown, Texas Meeting-San Francisco, Calif.

Applied Thermodynamics Chairman: W. C. Edmister, Calif. Res. Corp., 576 Standard Ave., Res. Corp., 576 Richmond, Calif.

Meeting-San Francisco, Calif.

Distillation Chairman: D. E. Holcomb, Dean of Eng., Texas Technological Col-lege, Lubbock, Tex. Meeting-St. Louis, Mo.

Dust and Mist Collection Chairman: C. E. Lapple, Dept. of Chem. Eng., Ohio State Univer-sity, Columbus 10, Ohio. Meeting-St. Louis, Mo.

Chairman: L. E. Stout, Dept. of Chem. Eng., Washington University, St. Louis 5, Mo.

Meeting-St. Louis, Mo. Use of Computers in Chemical Engineering

Chairman: John R. Bowman, Head, Dept. of Res. in Phys. Chem., Mellon Institute of Industrial Research, Pittsburgh 13, Pa. Meeting-St. Louis, Mo.

Heat Transfer

Chairman: D. L. Katz, Chairman Dept. Chem. & Met. Eng., Univ. of Mich., 2028 E. Eng. Bldg., Ann Arbor, Mich. Meeting—St. Louis, Mo.

Nuclear Engineering

Chairman: D. L. Katz, Chairman Dept. of Chem. and Met. Eng., Univ. of Mich., 2028 E. Eng. Bldg., Ann Arbor, Mich. Meeting-Ann Arbor, Mich.

Authors wishing to present papers at a scneduled meeting of the A.I.Ch.E. should first query the Chairman of the A.I.Ch.E. Program Committee, Loren P. Scoville, with a carbon copy of the letter to the Technical Program Chairman of the meeting at which the author wishes to present the paper. Another carbon should go to the Editor, F. J. Van Antwerpen, 120 East 41st Street, New York 17, N. Y. If the paper is suitable for a symposium, a carbon of the letter should go to the Chairman of the Symposia, instead of the Chairman of the Technical Program, since symposia are not scheduled for any meeting until they are complete and approved by the national Program Committee. Before authors begin their manuscripts they should obtain from the meeting Chairman a copy of the Guide to Authors, and a copy of the Guide to Speakers. The first book covers the preparation of manuscripts, and the second covers the proper presentation of papers are Judged at every meeting and an award is made to the apeaker who delivers his paper in the best manner. Winners are announced in Chemical Engineering Programs, and a scroll is presented to the winning author at a meeting of his local section. Since five copies of the manuscript must be prepared, one should be sent to the Chairman of the symposium and one to the Technical Program Chairman of the other three copies should be sent to the Editor's office. Manuscripts not received 120 days before a meeting cannot be considered.

# LOCAL SECTION NEWS

(Continued from page 71)

Edward A. White, publicity chairman of the El Dorado Section in Arkansas, from which area no news has come for several weeks, reports that a meeting was held on Jan. 23 with forty-nine members and guests in attendance. J. W. Bertetti, general manager of manufacturing for Pan-Am Southern Corp., spoke on Fluid Hydroforming. He reviewed the various process innovations, of which fluid hydroforming is the most recent, that have enabled petroleum refiners to increase both the quantity and the quality of gasoline recovered from the crude.

The following officers were elected for 1953 for the East Tennessee Section. They are E. L. Gustafson, chairman; R. O. Hubbard, vice-chairman; T. F. Reid, secretary-treasurer, and J. H. Jensen, director.

At the thirty-sixth general meeting held in the Foreman's Room of the Tennessee Eastman cafeteria, R. R. Cipolla, representative from Johns-Manville Co., answered questions in a discussion period after the showing of a film "Production and Use of Diatomaceous Silica Products." Benjamin Thompson, former secretary-treasurer, reported that the movie covered the use and preparation of celite and other Johns-Manville products as catalyst, catalyst supports, filter aids, etc. Twenty-two members and three guests attended the meeting.

Names of the officers of the Twin Cities Section for 1953, as reported by Russ Fredrickson, are: William Podas, Economics Lab., president; Russell Fredrickson, Minnesota Mining & Mfg. Co., vice-president; Robert Batey, Pillsbury Mills, secretary; Robert Callaghan, General Mills, treasurer, and Jose Calva, J. B. Calva Co., Neal Amundson, Univ. of Minnesota, and Fred Wehmer, Minnesota Mining & Mfg. Co., directors.

The Central Pennsylvania Chemical Engineers Club, a newly formed group, held its first 1953 meeting Jan. 21 at the Montour Hotel, Danville, Pa. After the formalities of a business meeting were disposed of, Richard H. Wilhelm, professor of chemical engineering at Princeton University, Princeton, N. J., and winner of the 1952 Professional Progress Award in Chemical Engineering, gave an address titled "New Developments in Mixing and Agitation." Lester Berkowitz, secretary of the Club, who conceived the idea originally of the benefits of such an organization in this area, is all agog over making this a live group that will meet regularly, hear well-informed speakers on current problems in chemical engineering and conscientiously take a leading part in solving the problems that confront chemical engineers.

Neil H. McKay, Jr., secretary of the South Texas Section, reports an interesting joint meeting with A.C.S. consisting

# Only a Filter Press Does So Many Jobs So Well

#### RECOVER SOLIDS

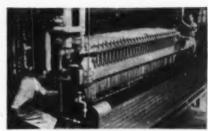
In firm, reasonably dry cakes easy to remove, handle and process.

## CLARIFY PERFECTLY

Crystal clear, even decolorize, deodorize and germproof, employing any required filter aids.

#### WASH OR EXTRACT

To recover or remove soluble contents from filter cake. Also steam, melt or redissolve cake.



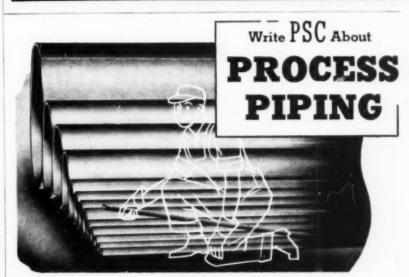
# UNDER ANY CONDITIONS

Of filtration pressure—even up to 1000 p.s.i.—at high or low temperature—on any material, even if heavy, thick, viscous, corrosive or abrasive.

Learn how Shriver Filter Presses—the most versatile in design, capacity and application—the most extensively used of all pressure filters—can do the job better for you at lower cost, Get Catalog 52.

# Shriver Filter Presses

T. SHRIVER & COMPANY, Inc., 812 Hamilton St., Harrison, N. J.



# Fabricated from Complete Range of Alloys, Any Diameter Up to 60", and in Any Shape

PSC welded process tubing is furnished in any alloy whatsoever. This feature accounts for its wide application in meeting the unlimited variety of heat, corrosion, oxidation conditions in process plants.

Any diameter up to 60"; wall thicknesses to 3/8"; temperatures to 2200°. Precision fabrication of tubing assemblies is a specialty. Send b/p or write as to your needs.

THE PRESSED STEEL CO., 708 N. Penna. Ave., Wilkes-Barre, Pa.

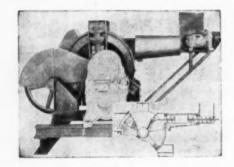
Custom Fabricators for the Process Industries Since 1928. Send Your Blue Prints



# OTARY DEWATERING PRESS

Greater capacity recovery efficiency profits

Delivers a dryer product



Available in two models-four sizes-either 5, 10, 15 or 20 ton rated capacity.

Most efficient method of extracting bulk water from semi-solids for profit in by-products and dehydrating operations.

Low Power Consumption-All Steel-Conserves Weight and Space.

Wherever used declared "The Best in the Business" welding & machine works, inc.

516 EAST LA PALMA ST. . ANAHEIM, CALIFORNIA k. Seattle, Baltimore, San Franciso t: Wilbur Ellis Company, San Francisco

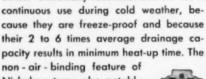
SIGNERS AND MANUFACTURERS OF DEHYDRATING EQUIPMENT

NICHOLSON MAKES

# Freeze-Proof Steam Traps

for every Plant Use

Because they drain completely when cold, these four types of Nicholson steam traps are positively freeze-proof. Can be freely installed outdoors. Universally recommended for use in lines which need not be in



TYPE AHV

Nicholson traps also notably facilitates heat transfer in severe weather. Types for every plant use. Size 1/4" to 2"; pressures to 250 lbs.



TYPE AU

214 OREGON ST., WILKES-BARRE, PA.

152

NICHOLSON)

TRAPS · VALVES · FLOATS

of an inspection trip to the Baylor University College of Medicine and the Laboratories of the M. D. Anderson Hospital. The program also included a social hour and dinner with Dr. J. O. Hirchfelder, director of the Naval Research Laboratory at Madison, Wis., and professor of chemistry at the University of Wisconsin, giving a talk on "Molecular Theory of Gases and Liquids." The names of the newly elected officers for 1953 were announced. These include J. J. McKetta, chairman-elect; Neil H. McKay, Jr., secretary; Guy T. McBride, Jr., treasurer, and W. L. Bolles and W. P. Schambra, executive committeemen. W. B. Franklin, 1952 chairmanelect, becomes chairman for 1953. A third executive committeeman is vet to be elected. This reporter is the same McKay, who was chairman of the South Texas Membership Committee, which showed the largest increase in membership applications among the sections.

Roger E. Larson reports the election of officers of the Northeastern New York Section for 1953 resulted as follows: Nolan Curry, Behr-Manning Corp., chairman; Austen W. Boyd, General Electric Co., Waterford, vice-chairman; Harry Steinhauser, Jr., R.P.I., Dept. of Chem. Eng., secretary, and Donald A. Waterfield, Behr-Manning

The importance of the chemical engineer in the work of the textile fibers department of Du Pont Co. was pointed out by Joseph B. Quig, manager, textile research division, textile fibers department, Du Pont, who addressed the Pittsburgh Section on Jan. 14 on synthetic fibers. Messrs. West, Morrissey and Black reported on this dinner meeting which was designated as Junior Member Night. Mr. Quig concluded his address by stating that most of the production problems in fiber manufacture are of an engineering nature and as new fibers are developed, new engineering problems will arise

At a recent meeting of the St. Louis Section Dr. David E. Morris, development engineer, Mallinckradt Chemical Works, was elected chairman of the Section for the coming year. Other officers elected were Dr. D. F. Chamberlain, dept. of chemical engineering, Washington University, vice-chairman; Dr. F. J. Holzapfel, Monsanto Chemical Co., secretary; A. T. Pickens, C. K. Williams Co., treasurer; C. P. Orr, Monsanto, executive committee member as retiring chairman. Charles W. Swartout, Mallinckrodt, has been appointed chairman of the 1953 National A.I.Ch.E. meeting to be held in St. Louis in December, 1953.

Under the editorship of E. H. Vause, the Chicago Section is getting out a worth-while newsletter containing some general news and some items on the activities of its members. (Editor's Note: Be sure we receive each issue.)

Sorry, no more space.-H.R.G.

# PEOPLE

The judging team at the Cleveland meeting of the A.I.Ch.E. decided im-



mediately after the close of the session on Dec. 10 that the award for the best presentation of a technical paper at the meeting should be given Prof. F. M. Tiller, director engineering, Lamar State College of Technology.

Beaumont, Tex. The paper, included in the Filtration Symposium, was titled "The Role of Porosity in Filtration, Part I."

This is not the first time that Professor Tiller has been singled out for recognition. He was the 1950 winner of the Junior Award of A.I.Ch.E. at the time he was associate professor of chemical engineering at Vanderbilt University. A native of Kentucky, Professor Tiller received a Ph.D. degree from the University of Cincinnati, where he was an instructor before going as assistant professor of chemical engineering to Vanderbilt later to become associate professor.

The presentation will be made at a meeting of Sabine Area Local Section in the near future.

Blythe M. Reynolds has been appointed to the newly created post of vicepresident for operations of Merck & Co., Inc. He joined the company in 1944 and has been director of engineering and purchasing since March, 1947. He became vice-president for engineering and purchasing in 1948. A graduate of Clarkson College of Technology, Potsdam, N. Y., Mr. Reynolds received an M.S. in chemical engineering from Massachusetts Institute of Technology in 1920. Mr. Revnolds served in World War I as a lieutenant in the Marine Corps and was for ten years with General Chemical Co., Marcus Hook, Pa., as a chemical engineer. He was president and general manager of his own company, Reynolds Chemical Corp., Utica, N. Y., from 1926 until 1930, when he sold the business to Heyden Chemical Corp. He was a vice-president of that organization until 1944.

Clarke L. Coldren recently joined the engineering staff of Shell Development Co., Emeryville, Calif. He obtained his bachelor's degree at Pennsylvania State College in 1948 and his M.S. and doctorate in chemical engineering at the University of Illinois in 1950 and 1952, respectively.

James A. Kapnicky was recently appointed research group leader in charge of the pilot plant at the Nitro, W. Va., laboratories of Monsanto Chemical Co.'s organic chemicals division according to an announcement by H. K. Nason, director of research. Kapnicky joined Monsanto at Nitro in January, 1952, as research section leader after an employment period with the Dow Chemical Co. as research project leader. A graduate of West Virginia University in 1943 with a B.S. in chemical engineering, he received his Ph.D. degree from the same university in 1950.

S. M. Cimino was transferred recently from the New York office where he was a member of the production department of Westvaco Chemical Division, Food Machinery and Chemical Corp., to the Newark plant as general superintendent. Mr. Cimino is a graduate of the University of California with a B.S. degree.

G. J. Visconty has been made a research associate in the engineering and economics section of Socony-Vacuum Oil Co., Inc., Paulsboro, N. J. He was employed by Magnolia Petroleum Co., a Socony-Vacuum affiliate, in 1942 after receiving a B.S. degree in chemical engineering from Case Institute of Technology. He has been with the research and development department since 1946.

Bradley Dewey, co-founder and president of Dewey and Almy Chemical Co. since its beginning thirty-four years ago, retired Dec. 31. At a ceremony held in the plant cafeteria he was presented with an illuminated testimonial from the employees of the various plants as a token of esteem. Mr. Dewey becomes chairman of the board.

Harry L. Hilleary has been appointed group leader at the Wood River, Ill., laboratory of Standard Oil Co.'s research department. Mr. Hilleary joined Standard in 1947 after graduating from Cornell University.

Allen N. Smith has recently joined the engineering department of San Joea



College in Son Jose, Calif. Dr. Smith was formerly associate professor of chemical engineering at the University of Louisville and has a Ph.D. degree from Oregon State College. He received his B.S. de-

gree in 1941 from Tulane University and in 1943 an M.S. degree from Georgia Tech.

(More News About People on page 76)







# PERSONNEL CHANGES AT MONSANTO

Effective Feb. 1, Norris Boehmer, who has been production superintendent at Monsanto's Nitro, W. Va., plant since January, 1952, became project chemical engineer of the organic chemicals division engineering department in St. Louis, Walter J. Meyer, who has been a general superintendent at the John F. Queeny plant in St. Louis, will take Boehmer's place as production superintendent at Nitro, and Robert E. Soden, area supervisor at Nitro, became a general superintendent at the John F. Queeny plant.

Boehmer, who received a B.S. degree in chemical engineering from the University of Utah in 1918, began with Monsanto in 1936 as production supervisor in the W. G. Krummrich plant at Monsanto, Ill. Employment in Monsanto laboratories which began in 1925, and periodic studies at Iowa State College led to a B.S. degree in chemical technology for Meyer from that school in 1933, when he went into the John F. Queeny plant as an assistant chemist. Soden joined Monsanto as an assistant chemist in the Akron. Ohio, sales office in 1939, after he had received his B.S. degree in chemistry from the University of Missouri. He also served at the W. G. Krummrich plant and at the Longhorn Ordnance Works, Marshall, Tex., operated by Monsanto during World War II, prior to assuming his present duties.

Jean R. Okel has been appointed division engineer of Monsanto Chemical Co.'s Western division. With his headquarters in Seattle, he will report directly to the general manager. He started in Monsanto in 1942 serving as a production supervisor in the organic chemicals division's John F. Queeny plant in St. Louis. In 1946 he was named project engineer and in 1948 became development superintendent of that plant, In June, 1951, he was named assistant to Charles Allen Thomas, now Monsanto president, who then was serving as executive vice-president. Mr. Okel received his B.S. in chemical engineering from the Washington University.

R. M. O'Flyng has recently been appointed resident production manager of the San Jose, Calif., plant of International Minerals & Chemical Corp. He had been manager of the division's development department since 1949. Prior to his joining the development department in 1945, he was a research and development engineer for American Potash and Chemical Corp. O'Flyng graduated from Stanford University with a B.S. in chemical engineering.

(More News About People and Necrology on page 78)

# CLASSIFIED SECTION

Advertisements in the Classified Section of Chemical Engineering Progress are payable in advance, and are placed at 15c a word, with a minimum of four lines accepted. Box number counts as two words. Advertisements average about six words a line. Members of the American Institute of Chemical Engineers in good standing are allowed one six-line insertion (about 36 words) free of charge per year. More than one insertion to members will be made at half rates. In using the Classified Section of Chemical Engineering Progress it is agreed by prospective employers and employees that all communications will be acknowledged, and the service is made available on that condition. Boxed advertisements are available at \$15 per inch. Size of type may be specified by advertiser. In answering advertisements all box numbers should be addressed care of Chemical Engineering Progress, Classified Section. 120 East 41st Street, New York 17, N. Y. Telephone ORegon 9-1560. Advertisements for this section should be in the editorial offices the 15th of the month preceding the issue in which it is to appear.

#### SITUATIONS OPEN

# SENIOR CHEMICAL ENGINEER

Experienced graduate chemical engineer required for large research and development organization in Northern Rhodesia. Duties relate to process metallurgy of copper, cobalt, lead, zinc and other base metals. Applicant must have minimum five years' industrial experience. Total remuneration approximately £2,400 per annum comprising basic salary, variable metal bonus, and cost of living allowance. Generous pension and leave privileges. Applications stating age, marital status, qualifications, experience record, availability, and accompanied by a recent photograph should be addressed to: The Secretary, P. O. Box 172, Kitwe, Northern Rhodesia.

#### **DEVELOPMENT ENGINEERS**

Chemical Engineers with strong theoretical background required for applied research and process development. Preference given to men with postgraduate degree and up to five years' process development experience.

Modern plant with excellent facilities and working conditions, located in Eastern Ontario, Canada.

Personal history including education and experience requested in first letter. Address inquiries to Box 1-2.

#### CHEMICAL ENGINEERS

For engineering research and development with a national food company. Qualifications include at least four years' experience preferably in some phase of process engineering. Salary

commensurate.

Please submit outline of experience, education, and salary required. Applications confidential.

Send replies to Box 6-2.

Urban midwestern college desires instructor in chemical engineering. Three to five years' industrial experience desired. Opportunity for advanced study and consulting. Rank and salary depending on background and capabilities. Write to:

DR. A. J. TELLER, Chairman Chemical Engineering and Chemistry Dept.

Fenn College Cleveland 15, Ohio

# PROCESS ENGINEER—Chemical engineer with exceptional individual initiative and four to six years' experience in petroleum refining to assume new position with independent company located in north Texas. Send complete résumé to: Box 3-2.

AN EXPANDING MEDIUM-SIZED FIRM—Located in Connecticut since 1832 has an opening with excellent opportunities in their Sales Department for a qualified man to cover western Pennsylvania, central and southern Ohio, parts of Kentucky, West Virginia and Indiana. Desirable to have an engineering degree or engineering background, preferably with sales experience, but not necessary. Should be between 25 and 35 years of age. Guaranteed earnings plus expenses the first year; straight commission plus expenses thereafter. This organization is a creator and fabricator of unique fibrous and plastic materials. Interested men are invited to write for further particulars and submit a résumé of their experiences and training a recent photograph and salary expected. Box 5-2.

#### LIKE PROBLEMS?

# CHEMICAL ENGINEER FOR DEVELOPMENT

Leading medium size Chemical Company desires Chemical Engineer with interest in development work in plastics field. Must have some mechanical engineering experience or aptitude. Location near Buffalo. Include résumé with your letter.

Reply Box 7-2.

#### CHEMICAL ENGINEER—To act as production consultant for chemical plant in eastern Ohio. Experience with commercial roasting, leaching, washing, filtering and electrolytic equipment desirable. Salary commensurate with background and experience. Opportunity with expanding company. Send complete résumé and salary information. Interviewa arranged, Box 28-2.

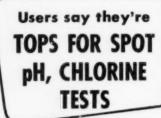
TECHNICAL SALESMEN—Rapidly growing medium sized chemical company serving the plastics and related industries requires services of three ambitious men 23 to 35, for sales department. Only those vitally interested in increasing personal income through productive effort and who are capable of carrying heavy responsibility dealing with large industrial accounts need apply. Starting salaries in line with capabilities and experience. Must be willing to travel—will be home week enda Company furnished car. One to five years' sales experience desirable. Drive and ambition essential. Write Box 4-2, New York, N. Y.

#### SITUATIONS WANTED

#### A.I.Ch.E. Members

- ENGINEERING MANAGER AVAILABLE—
  Chemical engineer with background in
  complete plant design and preparation and
  analysis of budgets for existing and proposed industrial installations. Bulk of
  previous experience in detergent, pharmaceutical, and organic chemicals fields.
  Metropolitan N. Y. preferred. Box 2-2.
- CHEMICAL ENGINEER B.S.Ch.E. Registered chemical and civil engineer. Seven years of excellent industrial experience with responsible positions in engineering and production trouble shooting. Desire position with chemical or consulting firm on West Coast. Family. Box 8-2.
- PRODUCTION DEVELOPMENT MANAGE-MENT—Registered professional chemical engineer. 44. Experience 23 years intricate technology, virtually all unit operations. Last 14 years top supervisory capacity. Has thoroughly exercised modern tools of management for development enthusiastic, efficient organizations. Recognized accomplishments. Interested heaviest responsibilities only. Available reasonable notice. Box 9-2.
- PROJECT MANAGER—B. Eng. (Chem.)
  McGill, 1941. Army officer, (engineering),
  process engineer, plant
  project manager. Age 32, \$9000 a year
  for last two years, desire change with
  opportunity for part ownership. Prefer
  continuing in petroleum refining or petrochemicals, but not limited. Box 10-2.
- CHEMICAL ENGINEER—Ph.D. Age 31.
  Family. Six years of industrial experience in research and development. 2½ years of full-time teaching (includes graduate level). Desire research or development position. Prefer amail town location. Box 11-2.
- MAINTENANCE AND DESIGN—B.Ch.E. Age 37, family, veteran. Seven years chemical plant maintenance supervision and design. Good management training, organizational ability. Experienced labor relations. Desire position as plant engineer. Present salary \$8,400. Box 12-2.
- CHEMICAL ENGINEER—Ch.E. 1950. Married. 35. Tau Beta Pi, seglatered (examination) veteran. Experienced waste disposal, research and development, administration. Management caliber. Desire responsible position as executive assistant or in development. Box 13-2.
- CHEMICAL ENGINEER—B.S. 1946. Married, veteran. Four years' experience pilot plant work, laboratory and field scale equipment. 2½ years plastics testing and evaluation. Interested in development or production preferably involving plastics. Box 14-2.
- EXECUTIVE-ENGINEER Desire position with strong, progressive organization which can use knowledge of manufacturing, administration and engineering; and offers possibility of advancement. Graduate chemical engineer and business administration. Nineteen years' diversified experience. Age 41. Box 15-2.
- CHEMICAL ENGINEER—B.S. 1945. Age 28, single. Eight years' experience in production and development in organic synthesis. Excellent references. Desire production supervisory position or will consider responsible position with travel. Box 16-2.
- CHEMICAL PRODUCT ENGINEER M.S.E.
  Ten years' development and plant experience desire responsible engineering position with growing company. Challenging work and opportunity for advancement essential. Midwest preferred. Box 17-2.
- CHEMICAL ENGINEERING ECONOMIST—
  M.S. Young, energetic. One year sales, four years economics. Desire position of opportunity with expanding firm. Presently heads small section doing product, process evaluation and design. Mostly organics \$7,500 minimum. Box 18-2.
- CHEMICAL ENGINEER—B.Ch.Eng. New York University. 1951. World War II and Korean veteran. Married. Well grounded in chemistry, mathematics and physics, and mechanically inclined. Desire position with opportunity and advancement in the New Jersey or metropolitan area. Box 19-2.

(More Ads on page 78)





Taylor Model T-O Comparator for pH. Silides available for pH as low as 0.2 or as high as 13.6. Phosphate slides work on same base. Chlorine comparators also available.

# TAYLOR COMPARATORS

GUARANTEED COLOR STANDARDS

EASY TO USE --

Taylor Comparators use the familiar colorimetric method of comparison . . . but without the need for handling fragile single standards. Each complete set of Taylor Liquid Color Standards in sturdy plastic slide, many slides usable on one base.

# FAST TO USE --

many determinations can be made in a matter of seconds, others take no longer than two minutes.

# CONVENIENT TO USE --

you can carry the lightweight set to the testing spot, no necessity for carrying solution samples back to the lab.

# ACCURATE TO USE --

because all Taylor Liquid Color Standards are unconditionally guaranteed against fading, thus there is no chance of mechanical inaccuracy.

WANT TO KNOW MORE?



See your leb supply dealer for Taylor sets or write direct for free copy of this informative handbook, "Modern pH and Chiorine Control". Describes theory of pH and chlorine control, illustrates full Taylor line.

W. A. TAYLOR AND CO.

PEOPLE

(Continued from page 76)

Ruben Zadigan has been appointed district manager in the western New York and western Pennsylvania area by the Dicalite Division of Great Lakes Carbon Corp. Dicalite headquarters for this area are in Buffalo. Mr. Zadigan is a graduate of the University of Kansas, receiving his Bachelor's degree in 1938. After serving thirty-one months overseas in the Middle East as a captain in the Corps of Engineers, he resumed his studies at the Graduate School of Brooklyn Polytechnic Institute. Prior to joining Dicalite he was associated with National Brewers' Academy of New York as a technical sales representative.

P. H. Groggins has been engaged as general chemical consultant by the administrative office for the chemical divisions of Food Machinery and Chemical Corp., New York. On Jan. 1, 1953 he retired from a twenty-six-year term of service in the employ of the U. S. Government where he had long been connected with the Department of Agriculture, and more recently, with N.P.A. Mr. Groggins is editor in chief of "Unit Processes in Organic Synthesis." which in its successive editions, has been a standard reference book in the chemical engineering field.

Robert W. Cairns, assistant director of research for Hercules Powder Co. since 1945, has been named vice-chairman of the research and development board, a staff agency of the Secretary of Defense. Dr. Cairns will be on loan to the government for one year, serving without compensation. In his new post, he will devote his full time to problems of national defense. Associated first with Hercules in 1934 as a research chemist at the experiment station, Dr. Cairns in 1940 was named assistant to the director of research. The following year he was named director of the experiment station. He attended the University of California and Oberlin College, receiving his B.A. degree from the latter in 1930, and a Ph.D. degree from Johns Hopkins University in 1932.

On Feb. 1, William P. Gage became president and a director of the Grace Chemical Co., wholly owned subsidiary of W. R. Grace & Co., New York, Mr. Gage has been vice-president in charge of manufacturing of the Shell Chemical Corp. since 1941. He joined the Shell Oil Co. in 1929 at its research laboratory in Wood River, Ill. He also served as head of the gas department and as assistant superintendent of Shell's Houston refinery, and later was head of the research and development department at Shell's head office.

Thomas J. Walsh, a member of the Case Institute of Technology faculty since 1947, has been promoted to professor of chemical engineering. Dr. Walsh received the Junior Technical Award of the Cleveland Technical Societies Council in 1952 for his outstanding contributions to Cleveland industry. Aside from his duties as professor of chemical engineering, he is a consultant on fuels for the National Advisory Committee for Aeronautics.

# Necrology

W. W. WHITTEN, JR.

William M. Whitten, Jr., who was retired from the Du Pont Co., Wilmington, Del., died late last year. A graduate of the University of Michigan, he was at one time associated with the Pittsburgh Reduction Co., now the Aluminum Company of America. In 1907 he joined Du Pont and served in the chemical department in various capacities. Later he was made assistant chemical director.

# CLASSIFIED SECTION

(Continued from page 77)

CHEMICAL ENGINEER—Sc.D. (M.I.T.) 1949, B.E. (Yale) 1942. Age 32. Four years U. S. Army, including two years atomic energy work. 3½ years research and development. Publications. Ability to think talk and write with originality, clarity and force. Desire responsible supervisory position with small to medium sized company. Box 20-2.

EXPERIENCED ENGINEER—B.S. 1943. Experienced in organic chemical production, process development and process engineering. Desire production or engineering position with small to medium-sized company in Southeast. Married, one child. Box 21-2.

PETROLEUM REFINERY ENGINEER—B.S.Ch.E. Age 36. With twelve years' diversified experience in process, project, and sales engineering. Desire permanent responsible position. Box 22-2.

REGISTERED PROFESSIONAL ENGINEER—B.S.Ch.E. Age 30, family. Reserve Officer scheduled for release. Seven years' diversified industrial experience in production, research, process development, supervision and administration. Desire challenging position. Prefer Midwest. Box 26-2.

B. OF CH, E.—36, married, no children. With staff level administrative experience including research and development, product engineering, market research and sales. Seek administrative position preferably with client contact opportunities and involving new product development and application. Box 27-2.

CHEMICAL ENGINEER—M.S. Age 27. Six years' experience in research development, production of pharmaceuticals, antibiotics, synthetic organics. Trouble shooting, administrative responsibilities. Desire responsible engineering position with progressive company. Box 29-2.

#### Nonmembers

ELECTRICAL ENGINEER—B.S.E.E. 37, married, veteran. Estimating, design, supervision of power, control, telemetering, carrier, radio, instruments, cathodic protection installations. Industrial, pipe line. Box 24-2.

CHEMICAL ENGINEER—Thirty years' experience in non-ferrous metals and inorganic. Perfect knowledge of technical French and German. Capable of translating and abstracting. Box 25-2.

# INDEX OF ADVERTISERS

	Page
Adams Co., Inc., R. P.  Aerofin Corporation  American Instrument Co., Inc.  American Pulverizer Co.	76 40 66 66
Barnstead Still & Sterilizer Co. Bartlett & Snow Co., The C. O. Brookfield Engineering Labs., Inc. Brown Fintube Co. Buflovak Equipment Division	71 28
Cameron Pump Div., Ingersoll-Rand Carpenter Steel Co. Climax Molybdenum Company Condenser Service & Engineering Co., Inc. Cooper Alloy Foundry Co. Cooper Hewitt Electric Co. Corning Glass Works Crane Company Croll-Reynolds Company, Inc.	12 67 58 39 65 51 6
Davis Engineering Co. Dollinger Corporation Dorr Company Dow Chemical Co. Duriron Co., Inc., The	. 14
Eimco Corporation	. 49
Fansteel Metallurgical Corp. Fischer & Porter Co. Fluor Corp., Ltd., The Food Technology, Inc. Foster Wheeler Corp. Foxboro Co.	. 17 . 76
Garlock Packing Co., The	
Inside Front Cover,	
General Industrial Development Corp	7
Girdler Corp.  Great Lakes Carbon Corp., Electrode Div	. 35 i-
Gruendler Crusher & Pulverizer Co	. 22
Hammel-Dahl Company	. 42
Hills-McCanna Co	
Ingersoll Rand, Cameron Pump Div.	. 25
	16, 80
Kinney Manufacturing Co.	. 29
Lapp Insulator Co. Ledeen Mfg. Co. Louisville Drying Machinery Unit, Gener	. 75
American Transportation Corp	. 33
Minneapolis-Honeywell Regulator Co	
Nagle Pumps, Inc. National Carbon Co., A Division of Unio Carbide and Carbon Corp. Newark Wire Cloth Co. Niagara Blower Co. Nicholson & Co., W. H.	. 8,9 . 62
Ohmart Corp., The	. 60
P & L Welding & Machine Works, Inc	. 74
Pacific Valves, Inc.	13

# **Advertising Offices**

New York 17-Lansing T. Dupree, Adv. Mgr.; Paul A. Jolcuvar, Dist. Mgr.; 120 E. 41st St., Oregon 9-1560.

Chicago 4-Richard R. Quinn, Dist. Mgr., 20 E. Jackson Blvd., Room 800, Webster 9-2225.

Cleveland 15-Douglas H. Boynton, Dist. Mgr., 1836 Euclid Ave., Superior 1-3315.

Pasadena 1—Richard P. McKey, Dist. Mgr., 465 East Union St., Ryan 1-8779.

Po	ge
	73 30
The second secon	36 37
Sparkler Manufacturing Co	73 41 18
Sperry & Co., D. R	70 68 71
Submerged Combustion Company of Amer-	54
Swenson Evaporator Co., Div. of Whiting Corp	ver

Thermal Syndicate, Ltd. Trane Co.  Uehling Instrument Co. Union Carbide and Carbon Corp., National Carbon Co.  U. S. Electrical Motors, Inc. U. S. Stoneware Co.  Vernon Tool Co., Ltd.  Vulcan Copper & Supply Co., Inside Back Co.  Western Precipitation Corp.  Whiting Corp., Swenson Evaporator Div., Back Co.  Wiggins Gasholder Div. Inside Front Co.	Page
Thermal Syndicate, Ltd. Trane Co.  Uehling Instrument Co. Union Carbide and Carbon Corp., National Carbon Co.  U. S. Electrical Motors, Inc. U. S. Stoneware Co.  Vernon Tool Co., Ltd. Vulcan Copper & Supply Co., Inside Back Co. Western Precipitation Corp. Whiting Corp., Swenson Evaporator Div., Back Co. Wiggins Gasholder Div., Inside Front Co. Wyssmont Co.	W. A 78
Uehling Instrument Co. Union Carbide and Carbon Corp., National Carbon Co. U. S. Electrical Motors, Inc. U. S. Stoneware Co.  Vernon Tool Co., Ltd.  Vulcan Copper & Supply Co., Inside Back Co.  Western Precipitation Corp.  Whiting Corp., Swenson Evaporator Div., Back Co.  Wiggins Gasholder Div., Inside Front Co.  Wyssmont Co.	
Union Carbide and Carbon Corp., National Carbon Co. 8 U. S. Electrical Motors, Inc. U. S. Stoneware Co. Vernon Tool Co., Ltd. Vulcan Copper & Supply Co., Inside Back Co. Western Precipitation Corp. Whiting Corp., Swenson Evaporator Div., Back Co. Wiggins Gasholder Div., Inside Front Co. Wyssmont Co.	
Carbon Co. 8 U. S. Electrical Motors, Inc. U. S. Stoneware Co.  Vernon Tool Co., Ltd.  Vulcan Copper & Supply Co., Inside Back Co.  Western Precipitation Corp.  Whiting Corp., Swenson Evaporator Div., Back Co.  Wiggins Gasholder Div., Inside Front Co.  Wyssmont Co.	nent Co
U. S. Electrical Motors, Inc. U. S. Stoneware Co.  Vernon Tool Co., Ltd.  Vulcan Copper & Supply Co., Inside Back Co.  Western Precipitation Corp.  Whiting Corp., Swenson Evaporator Div., Back Co.  Wiggins Gasholder Div	and Carbon Corp., National
U. S. Stoneware Co.  Vernon Tool Co., Ltd.  Vulcan Copper & Supply Co., Inside Back Co.  Western Precipitation Corp.  Whiting Corp., Swenson Evaporator Div., Back Co.  Wiggins Gasholder Div. Inside Front Co.  Wyssmont Co.	8, 9
U. S. Stoneware Co.  Vernon Tool Co., Ltd.  Vulcan Copper & Supply Co., Inside Back Co.  Western Precipitation Corp.  Whiting Corp., Swenson Evaporator Div., Back Co.  Wiggins Gasholder Div Inside Front Co.  Wyssmont Co.	Motors, Inc 34
Vulcan Copper & Supply Co Inside Back Co. Western Precipitation Cerp. Whiting Corp., Swenson Evaporator Div., Back Co. Wiggins Gasholder Div Inside Front Co. Wyssmont Co	
Western Precipitation Cerp. Whiting Corp., Swenson Evaporator Div., Back Cor Wiggins Gasholder Div	o., Ltd
Whiting Corp., Swenson Evaporator Div., Back Co Wiggins Gasholder Div Inside Front Co Wyssmont Co	& Supply Co Inside Back Cover
Wiggins Gasholder Div Inside Front Co Wyssmont Co	
Wyssmont Co	Back Cover
Wyssmont Co	Ider Div Inside Front Cover
York Co., Inc., Otto H.	
The said mad some out to the territorial to the ter	Опо Н 71



CONTENTS ANY DISTANCE AWAY



GAUGES

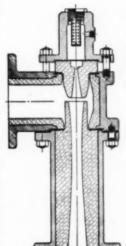
FOR ALL PURPOSES

HYDROSTATIC PRESSURE . VACUUM . DRAFT **DEPTH & ABSOLUTE PRESSURE BAROMETRIC PRESSURE DIFFERENTIAL PRESSURE** SEND FOR BULLETINS

CO. PATERSON, N. J.

# C-R EVACTORS

# MEET CORROSION PROBLEMS



The chemical industries are employing more and more Croll-Reynolds Evactors in vacuum processes where corrosion resistance is a major consideration. These steam jet vacuum units provide pressures ranging from a few inches to a few microns. Croll-Reynolds is a pioneer in the use of new construction materials and our engineers are investigating corrosion problems continually.

Stainless steels, Monel metal, Beryllium copper, Ni-Resist, PMG metal, hard lead, special bronzes, Hastelloy, and Illium are but a few of the special metals which find their way into our equipment. Carbon is used extensively as a lining material, and many plastics including Teflon and synthetic materials are used for making complete Evactors.

Consult our engineers for high vacuum equipment carefully designed for your specific conditions, and constructed of materials selected for your particular conditions.



# CROLL-REYNOLDS CO., INC.

Main Office: 751 Central Avenue, Westfield, New Jersey New York Office: 17 John Street, New York 38, N. Y.

CHILL-VACTORS STEAM JET EVACTORS CONDENSING EQUIPMENT Cuteway drawing shows how J-M Weather-Protected Insulation is applied to tanks such as those at the S. D. Warren Company paper mill. Standard methods for mechanical securement of the insulation are used. Asbestocite sheets are then applied over the insulation, in accordance with the simplified Johns-Manville specification.

A (Above) Completed job of J-M Weather-Protected Insulation on black liquor tanks of the S. D. Warren Company.

(Right) Skilled applicators of an outstanding J-M Insulation P Contractor, P. S. Thorsen Co. of South Boston, Mass., applying

# S. D. Warren Company saves fuel, reduces maintenance on outdoor tanks with J-M <u>Weather-Protected</u> Insulation

On black liquor tanks of the S. D. Warren Company paper mill at Cumberland Mills, Maine, Johns-Manville Weather-Protected Insulation pays a "double dividend":

Asbestocite sheets over Zerolite insulation.

It saves money on fuel and maintenance. J-M Zerolite\* insulation keeps the heat in... thereby saving a substantial amount in fuel costs. J-M Asbestocite\*, a strong asbestos-cement sheet material, covers the Zerolite Insulation to protect it both from the weather and from wetting due to normal plant operations. This "bodyguard" layer of Asbestocite Weather Protection makes the tanks virtually maintenance-free and helps hold down operating costs.

It helps provide close temperature control. The temperature of black liquor in these tanks must be maintained so that it will flow freely and not clog up pumping apparatus. J-M Weather-Protected Insulation helps do the job dependably and economically.

Whatever the operating temperature of outdoor tanks and vessels, Johns-Manville offers the right insulation for application under the Asbestocite weather protection. For example, J-M 85% Magnesia Insulation is also widely used for this service because of its proved performance for temperatures to 600 F.

To be sure that the insulation and its weather protection is properly applied to pay the greatest return on your investment, J-M offers the services of experienced J-M Insulation Engineers and J-M Insulation Contractors. These men stand ready to give you an insulation job that will more than pay off your initial investment through maximum fuel savings.

For further information about J-M Weather-Protected Insulation, write to Johns-Manville, Box 60, New York 16, New York. In Canada, 199 Bay Street, Toronto 1, Ontario.

\*Reg. U.S. Pat. Off.

# Johns-Manville FIRST IN INSULATION

MATERIALS . ENGINEERING . APPLICATION

# special designs

# IN FRACTIONATING TOWERS

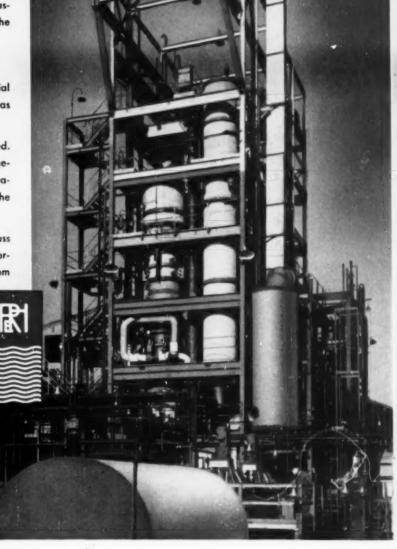
These towers are part of a unit for producing raw materials used in the manufacture of the acrylic plastic, Plexiglas, at the Bristol, Pennsylvania plant of the Rohm & Haas Company.

The towers were designed and built by Vulcan.

Process requirements presented a number of special problems in tower design since heavy construction was specified along with a high degree of accessibility.

All joints in the two copper towers are copper-welded. Extreme weight called for special supporting arrangements at the midsections. A special entrainment separator was designed for the top section of one of the copper towers.

Vulcan Manufacturing Division will be glad to discuss with you your special problems. An experienced organization capable of designing and fabricating from any workable material is at your service.



# VULCAN MANUFACTURING DIVISION

The VUICAN COPPER & SUPPLY CO.,
General Offices and Plant, CINCINNATI 2, OHIO

NEW YORK BOSTON PHILADELPHIA SAN FRANCISCO VICKERS VULCAN PROCESS ENGINEERING CO., LTD., MONTREAL, CANADA

DIVISIONS OF THE VULCAN COPPER & SUPPLY CO.

# This man has information on over 1000



# The Combined Experience of all Swenson Engineers Assures Better Processing at LOWER COST For You!

Chemical processing firms throughout the world have been helped by Swenson engineers in the development of over one thousand evaporator installations! The problems encountered and the solutions effected are known by every one of our engineers—and you can have this combined experience—just for the asking.

Swenson engineers saved these firms large sums of money and helped greatly to speed the production of uniform, quality products. Previous experience and its application to each particular problem was an important reason for such accomplishments. Outstanding results have also been attained in many hundreds of filtration, crystallization and drying installations.

So use Swenson experience! Talk to a Swenson Engineer now...before you plan so that he can help you plan. Let him do much of the "tough" work... analysis, layout and design, and recommendation of equipment. You will be assured of an installation that meets every specific requirement!

#### SWENSON EVAPORATOR COMPANY

15690 Lathrop Avenue Harvey, Illinois













CRYSTALLIZERS



ENTERS